Technical Report Documentation Page

1. REPORT No.

FHWA-CA-TL-86/11

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE

Recycling Asphalt Concrete
(Experimental Construction)

5. REPORT DATE

June 1986

6. PERFORMING ORGANIZATION

7. AUTHOR(S)

T. Scrimsher

8. PERFORMING ORGANIZATION REPORT No.

633159

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Office of Transportation Laboratory
California Department of Transportation
Sacramento, California 95819

10. WORK UNIT No.

11. CONTRACT OR GRANT No.

F76TL06

12. SPONSORING AGENCY NAME AND ADDRESS

California Department of Transportation
Sacramento, California 95807

13. TYPE OF REPORT & PERIOD COVERED

Final

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This report was prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

This report documents the construction and performance of hot asphalt concrete recycling on three projects located on Route I-5 at Weed, Route I-80 at Gold run and Route I-10 at Blythe. In addition, various cold and one hot surface recycled projects are discussed.

Also, information is presented on recycling pavements containing various fabrics and use of the nuclear gage to determine asphalt contents for recycling.

Two California test methods for design of recycled mixture are presented, one for hot and one for cold recycling.

17. KEYWORDS

Recycled AC, asphalt concrete, salvaged AC, reclaimed asphalt pavement, cold planner, CMI, drier drum, fabric, Troxler Nuclear Gage, vacuum extractor, recycling agents, RAP

18. No. OF PAGES:

174

19. DRI WEBSITE LINK

http://www.dot.ca.gov/hq/research/researchreports/1981-1988/86-11.pdf

20. FILE NAME

86-11.pdf

86-11

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

RECYCLING ASPHALT CONCRETE
(Experimental Construction)

Study Supervised by .... Robert N. Doty, P.E.

Principal Investigator .... Roger Smith, P.E.

Co-Investigator .... Thomas Scrimsher, P.E.

Report Prepared by .... Thomas Scrimsher, P.E.

RAYMOND A. FORSYTH, P.E.
Chief, Office of Transportation Laboratory

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
FHWA-CA-TL-86/11		

4. TITLE AND SUBTITLE
RECYCLING ASPHALT CONCRETE
(Experimental Construction)

5. REPORT DATE
June 1986

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
T. Scrimsher

8. PERFORMING ORGANIZATION REPORT NO.
633159

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Office of Transportation Laboratory
California Department of Transportation
Sacramento, California 95819

10. WORK UNIT NO

11. CONTRACT OR GRANT NO.
F76TL06

12. SPONSORING AGENCY NAME AND ADDRESS
California Department of Transportation
Sacramento, California 95807

13. TYPE OF REPORT & PERIOD COVERED
Final

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
This report was prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT
This report documents the construction and performance of hot asphalt concrete recycling on three projects located on Route I-5 at Weed, Route I-80 at Gold Run and Route I-10 at Blythe. In addition, various cold and one hot surface recycled projects are discussed.

Also, information is presented on recycling pavements containing various fabrics and use of the nuclear gage to determine asphalt contents for recycling.

Two California test methods for design of recycled mixture are presented, one for hot and one for cold recycling.

17. KEY WORDS
Recycled AC, asphalt concrete, salvaged AC, reclaimed asphalt pavement, cold planer, CMI, drier drum, fabric, Troxler Nuclear Gage, vacuum extractor, recycling agents, RAP.

18. DISTRIBUTION STATEMENT
No Restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. SECURITY CLASSIF. (OF THIS REPORT)	20. SECURITY CLASSIF. (OF THIS PAGE)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified		

DS-TL-1242 (Rev.6/76)

NOTICE

The contents of this report reflect the views of the Office of Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Neither the State of California nor the United States Government endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the object of this document.

CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2) square feet (ft^2) acres	6.432×10^{-4} .09290 .4047	square metres (m^2) square metres (m^2) hectares (ha)
Volume	gallons (gal) cubic feet (ft^3) cubic years (yd^3)	3.785 .02832 .7646	litre (l) cubic metres (m^3) cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s	28.317	litres per second 1/s)
	gallons per minute (gal/min)	.06309	litres per second (1/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G) (ft/s^2)	9.807	metres per second squared (m/s^2)
Density	(lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) (1000 lbs) kips	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British termal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (in-lbs) foot-pounds (ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch ($ksi\sqrt{in}$)	1.0988	mega pascals$\sqrt{metre}$ ($MPa\sqrt{m}$)
	pounds per square inch square root inch ($psi\sqrt{in}$)	1.0988	kilo pascals$\sqrt{metre}$ ($KPa\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{+F - 32}{1.8} = +C$	degrees celsius (°C)

ACKNOWLEDGEMENT

Appreciation for contributions to this report are extended to personnel in Caltrans Districts 2, 3, 4, 6, 8, 9 and 11 where recycling has been completed and studied.

In addition, appreciation is expressed to the contractors for their cooperation, and also to the following TransLab personnel: Jack Van Kirk for his editorial assistance, Roger Smith and Ken Iwasaki for their data on fabrics, and Al Rybicki, Ron Morrison and Glenn Kemp for their laboratory work and Lydia Burgin for the word processing.

TABLE OF CONTENTS

Page

INTRODUCTION 1

FINDINGS AND CONCLUSIONS 5

A. General 5

B. Cold-in-Place Recycling 6

C. Hot Recycling 7

D. Hot Surface Recycling 9

1. Heater Scarifier 9

E. Fabric Effect on Recycling 9

F. Nuclear Asphalt Content Gage 10

G. Blythe Failure 10

IMPLEMENTATION 11

DISCUSSION 12

A. Types of Recycling (General) 12

B. Milling or Pulverization of Old AC 13

C. Sizing of RAP Material 19

D. Laboratory Design for Recycled Mixes 26

1. General 26

2. Recycled Mix Formula 29

3. Gradation of the Milled RAP 30

4. Establishing a Lab Maximum Density 34

a. Cold Recycling 34

b. Hot Recycling 41

5. Stability 41

6. Cohesion 43

TABLE OF CONTENTS (cont.)

	Page
7. Grade and Amount of Binder	43
E. Mixing and Placing of Recycled Mixes	49
1. Cold Recyling	49
a. Mixing and Placing	50
b. Compaction Equipment	52
2. Hot Recycling	54
F. Hot Plant Control - Using a Vacuum Extractor vs. a Nuclear Asphalt Content Gage	56
G. Performance of Recycled Mixes	57
1. Hot Recycled Mixes	57
2. Cold Recycled Mixes	78
3. Hot Surface Recycling	81
H. Recycling AC Mixes That Contain Paving Fabric	83
I. Energy Saving Estimate	87
J. Cost Analysis	87
K. Summary	87
L. Need For Additional Research	88
REFERENCES	93-99
APPENDIX A Test Procedures	A-1
1. Design of Hot Recycled Mixes	
2. Design of Cold Recycled Mixes	
3. Monitoring Asphalt Content in Hot Recycling	
APPENDIX B Recycling AC Containing Fabric	B-1

LIST OF FIGURES

		Page
1.	One Advantage of Recycling	2
2.	Ripping AC Pavement	14
3.	Pulverizing Ripped Pavement	14
4.	Portable Crusher	14
5.	Cold Milling AC Pavement	14
6.	Milling Machines with Cat Tracks	15
7.	Milling Machines with Rubber Tires	16
8.	Conical and Wedge Milling Teeth	18
9.	Conical Tooth (C3)	18
10.	Spiral Setting for Teeth on the Mandrel	18
11.	Crushing Oversize After Milling	20
12.	Entire Recycling Train	20
13.	Screen for Removing Oversize RAP, Prior to Heating (Grizzly)	20
14.	Testing for Density with A Nuclear Gage	36
15.	Preparing Laboratory Compacted Specimens with the California Kneading Compactor	36
16.	Moisture Effect on Testing	40
17.	Hveem Stabilometer	40
18.	California Cohesiometer	44
19.	Design Nomograph	44
20.	Midland Paver	51
21.	The Valentine Recycle Train	51
22.	The Gardner Mixer	51
23.	Seaman Mixer	53

LIST OF FIGURES

Page

24. Dynapac Vibratory Roller 53

25. Bros Pneumatic Roller 53

26. Batch Plant Converted for Recycling 55

27. Drier Drum Converted for Recycling 55

28. Conventional AC Paving Machine 55

29. Blythe Project Location - Route 10 66

30. Surface Cracking on Route 10 68

31. Surface Bleeding on Route 10 68

32. Applying Reclamite on Route 10 69

33. Finished Test Area on Route 10 69

34. Removing Core from Pavement 71

35. Recovered Core to be Tested 71

36. Rte 178 - Inyokern - Fat Spot or "Surface Boils" Due to Moisture Vapor Action 80

37. Rte 178 - Inyokern - Rutting 80

38. Rte 178 - Inyokern - Rutting 80

39. Surface Raveling As A Result of A Surface Seal 82

40. Pavement Reinforcing Fabric 84

41. CMI Model 225 Roto Mill 86

42. Strips of Fabric After Milling 86

43. Fabric "Caking" on Mandrel 86

44. Three Completed Jobs - Barstow, Weed and Crowley 89

45. Pavement Cores From Cold Recycled Projects . . . 90

LIST OF TABLES

Page

1. Selection of Type of Recycling 3
2. Adopted Specifications for Hot Mix Recycling Agents 28
3. Grading vs Specific Gravity 31
4. Gradation of Salvaged AC Prior to Extraction (Cold Recycling) 32
5. Nuclear Gage Densities 35
6. Selection of Lab Fabrication 37
7. Abson Recovery Data (Field R/C Mix) 46
8. M_R Data (Cold Recycle) 47
9. Asphalt Content Comparison 58
10. Performance Record (Hot Recycling) 59-60
11. Performance Record (Cold Recycling) 61-62
11A. AC Recycling Projects 63
11B. Rating Criteria for Recycled AC 64
12. Reclamite Test Patch Locations 70
13. Reclamite Test Sections 72
14. Test Data (11-Riv-10) 75
15. Summary of Test Results - Paving Asphalt (11-Riv-10) 76

INTRODUCTION

Inflation, the decreasing availability of good quality aggregate, the possibility of a severe asphalt shortage if another petroleum embargo occurs, and the pressure to use gasoline tax funds for efforts other than roadway construction, rehabilitation, and maintenance have all contributed to the current critical problems regarding highways. If a substantial portion of the existing asphalt concrete (AC) pavement exhibiting major distress could be recycled, this would alleviate, at least to some extent, these problems in that recycling worn-out pavements potentially can save money, conserve resources, and reduce energy consumption. For example, on 4-lane roadways, frequently only 1 or 2 lanes need most of the attention. By recycling pavement in these lanes, the thick overlay that otherwise would be required on all the lanes can be avoided (Figure 1).

Several processes have been developed and are now being utilized to recycle asphalt concrete pavements. In general, recycling has been identified as any one of three processes: 1) hot central plant recycling, 2) cold-in-place recycling, or 3) hot surface recycling. The California Department of Transportation now has experience recycling asphalt pavement by each of the three processes.

The selection of the type of recycling depends on the type of pavement distress and the funds available (Table 1). Two interim reports have been published, each report covering the construction details of a specific project and process. One report(28) covered a project completed by the hot surface recycling (Route 36 - 1981) method and one report(27) covered a hot central plant recycling process (I-80-1979). During the study period of this project

SELECTION OF TYPE OF RECYCLING

(ASSUMING EVALUATION INDICATES EITHER RECYCLING OR AN OVERLAY)

PREDOMINATE DISTRESS	RECYCLING			OVERLAY
	HOT (A)	COLD (B)	SURFACE	
BLEEDING, RAVELING, AND/OR RUTTING <3/4"	3	4	1	2
RUTTING >3/4	1	2	4	3
CRACKING				
ALLIGATOR	1	3	4	2
TRANSVERSE	1	2	4	3
LADDER	1	2	4	3
LONGITUDINAL	1	2	4	3
BLOCK	1	2	4	3

1- 1ST CHOICE
2- 2ND CHOICE
3- 3RD CHOICE
4- NOT RECOMMENDED.

(A) USE UP TO 60% SALVAGED A.C. FOR DRIER DRUM PLANTS AND 40% FOR BATCH PLANTS IF AVAILABLE. NEW AGGREGATE NEEEDED FOR ONE OR MORE OF THE FOLLOWING REASONS:

a. MINIMIZE AIR POLLUTION
b. ADJUST FINAL AGGREGATE GRADATION
c. INCREASE LOAD CARRYING CAPACITY (GE) DUE TO HIGHER DESIGN TRAFFIC (TI).

(B) MUST BE PROTECTED WITH A MINIMUM 0.15' OF NEW AC

TABLE 1

FINDINGS AND CONCLUSIONS

A. General

(1) All methods of recycling studied are workable and may be used successfully.

(2) The method selected will depend upon the roadway condition, available materials, and funds available.

(3) Cold planing of an AC surface is an excellent method of removal which permits all or a portion of the AC to be recycled.

(4) The availability of cold planing machines has become widespread and thus milling or planing has become competitive.

(5) The Midland paver is an excellent machine to use for the in-place mixing and placing of recycled mixtures.

(6) One particular method of cold-in-place recycling involving a continuous train of equipment (CMI Roto-Mill, sizing machine and mixer all joined together) is an outstanding contribution to cold recycling.

(7) With any recycled mix, the laboratory design must include comprehensive testing to establish projected performance relative to surface flushing, raveling, and stability.

(8) Recycling is particularly advantageous when only the truck lane is distressed. By milling and recycling only in the distressed lane instead of placing a thick overlay

(5) Slight surface raveling will generally occur during the first 24 hours after traffic has been permitted directly on cold recycled AC(14A,13L).

(6) Fog seals used in an attempt to arrest surface raveling may cause pickup and magnify the surface abrasion problem(140).

(7) In spite of high void contents, cold recycled mixtures will carry traffic for short periods without undue rutting or pushing(14L).

(8) To protect a cold recycled mixture from eventual raveling or rutting, a blanket or "cap" of hot recycled or conventional AC should be placed.

(9) Moisture content of the recycled mix at the time the cap is placed should be no more than 1.5% in hot climates (max temp 100+) and 2.0% in cooler climates to avoid overlay damage of the overlay due to moisture vapor action.

(10) Cold recycling should be confined to a depth of 0.25' unless arrangements for compacting in more than one lift are made.

C. Hot Recycling

(1) The amount of "new" materials used can be decreased by recycling. This results in a savings of asphalt, virgin aggregate, and the total fuel needed to produce and dry virgin aggregate.

(2) Hot recycling can be successfully accomplished by either the drier drum method or by the batch plant method.

D. Hot Surface Recycling (Top 1 in. of Pavement

(1) Heater Scarifier

a) This type of recycling presently is not appropriate for pavements with severe distress that extends more than 3/4 inch below the original pavement surface.

b) The cost of surface recycling is about half that of a conventional 1 inch thick AC overlay.

c) The riding quality provided by surface recycling only the top 1 inch is somewhat inferior than that obtained with a 1" asphalt concrete overlay.

d) Hot surface recycling provides a good bond between the recycled mix and the old AC surface.

e) The use of an open flame applied to AC pavement patches and using diesel oil as fuel oil results in considerable air pollution.

E. Fabric Effect on Recycling

(1) The presence of fabric in an AC pavement does not seriously affect the milling of the pavement.

(2) For the four fabrics studied, the best milling (i.e., smallest fabric particles) occurred with the chisel tooth (CS2) at the slower travel speed.

IMPLEMENTATION

All three methods of recycling can be successful in the proper application. It appears that the cold-in-place method is gaining the most attention in California due to cost and the development of equipment and expertise. The hot central plant method is running a strong second in popularity due to the fact that these mixtures can be used for surfacing and can be expected to perform as well as conventional hot mixtures. The hot surface method, the least expensive method of all, is available for use on small scale rehabilitation projects where a polished or slick surface or surface raveling due to surface oxidation appear.

Recycling by one of the three methods will be promoted as appropriate for each Caltrans rehabilitation project.

A Policy and Procedure Memo P81-7 to all Caltrans Districts dated May 8, 1981 on Conservation of National Resources mandates the recycling of asphalt concrete materials "....unless it can be demonstrated that recycling will not result in a significant savings in energy, nonrenewable resources and cost".

A major revision (dated April 5, 1985) to the Caltrans Highway Design Manual was submitted concerning recycled mixtures.

the RAP is removed from the roadway and transported to a central plant. Without the use of heat, it is mixed with a recycling agent and then returned and placed in the street. Although this method has not been utilized on a state project in California to date, it has been effectively used in California by Merced County.

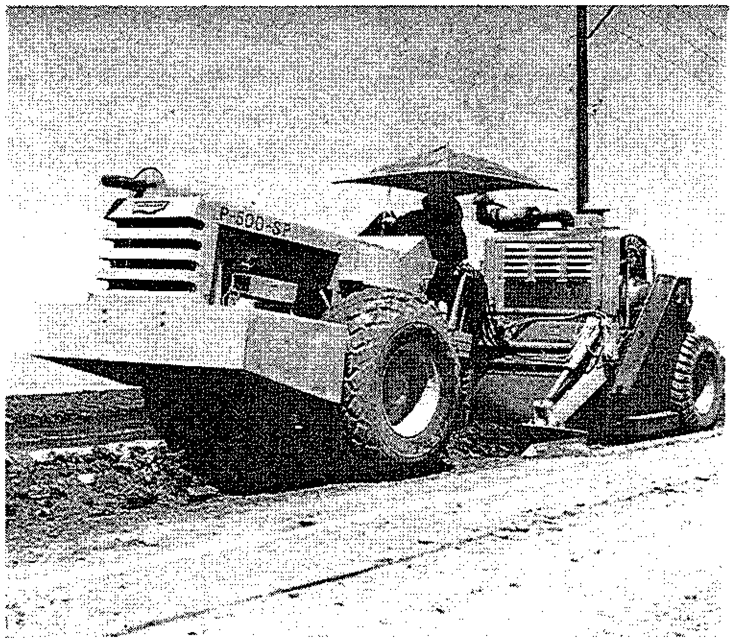
B. Milling or Pulverization of Old AC

In either cold-in-place or hot central plant recycling, all or a portion of the mixture in the roadway must be removed and/or pulverized for recycling. In California, several methods have been used. In situations where the entire thickness of AC pavement was to be removed, it has been 1) ripped into chunks (Figure 2) and then pulverized in place with either grid rollers or a hammermill (Figure 3), 2) removed and then pulverized in a portable aggregate crusher (Figure 4), or 3) removed by a cold milling machine (Figure 5). If only a portion of the AC thickness was to be removed, it has always been removed by a milling machine.

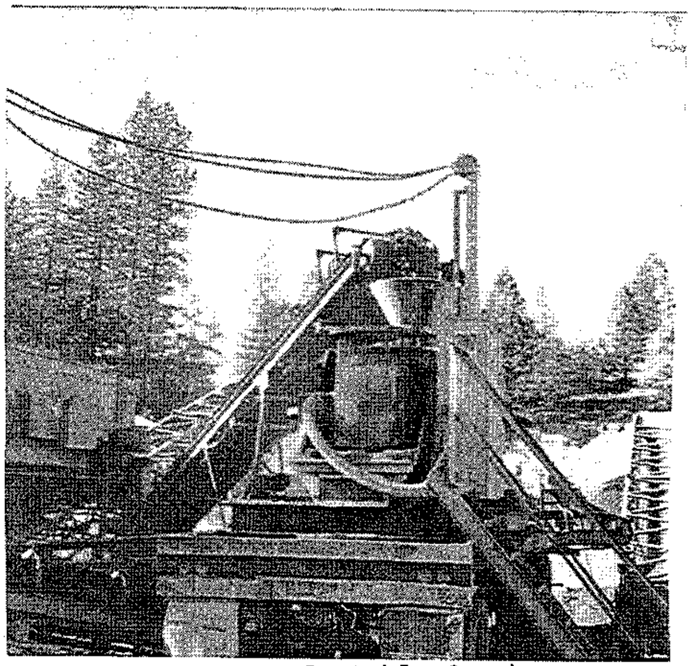
With the cold milling machine, it is possible to accurately mill off from 0.1 to 0.4 ft of the AC pavement in widths per pass varying from 2.0 to 12.5 ft and maintain a grade tolerance to within 0.05 ft. Currently, many manufacturers produce machines. Some of the machines that have been used in California are: Roto Mill, Dynaplane, RayGo, Eager Beaver and the Galion (Figure 6 and 7).

The teeth used for milling have been used in mining machines for many years. There are two general types

Ripping AC Pavement
Figure 2



Pulverizing Ripped Pavement
Figure 3



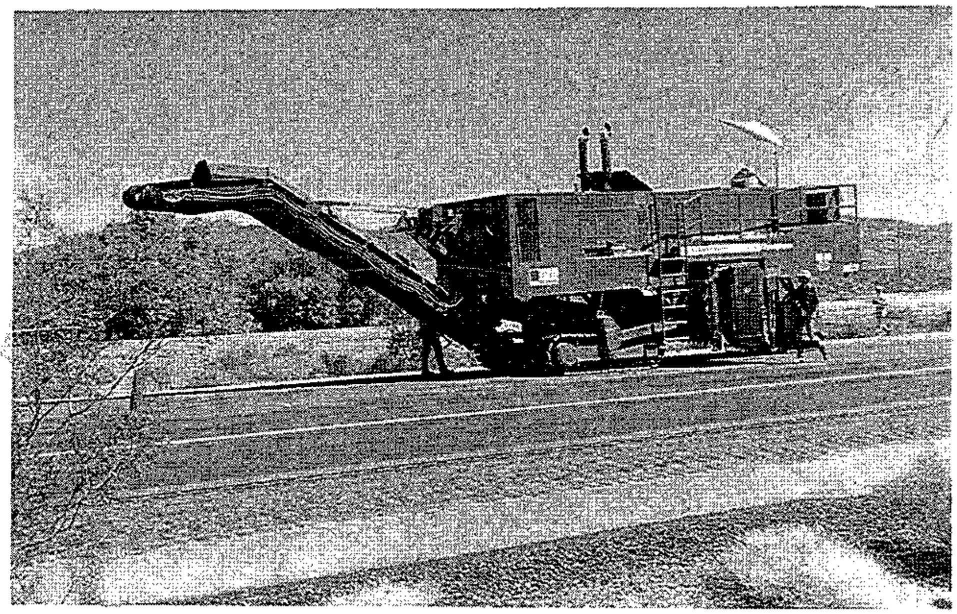
Portable Crusher
Figure 4

Cold Milling AC Pavement
Figure 5

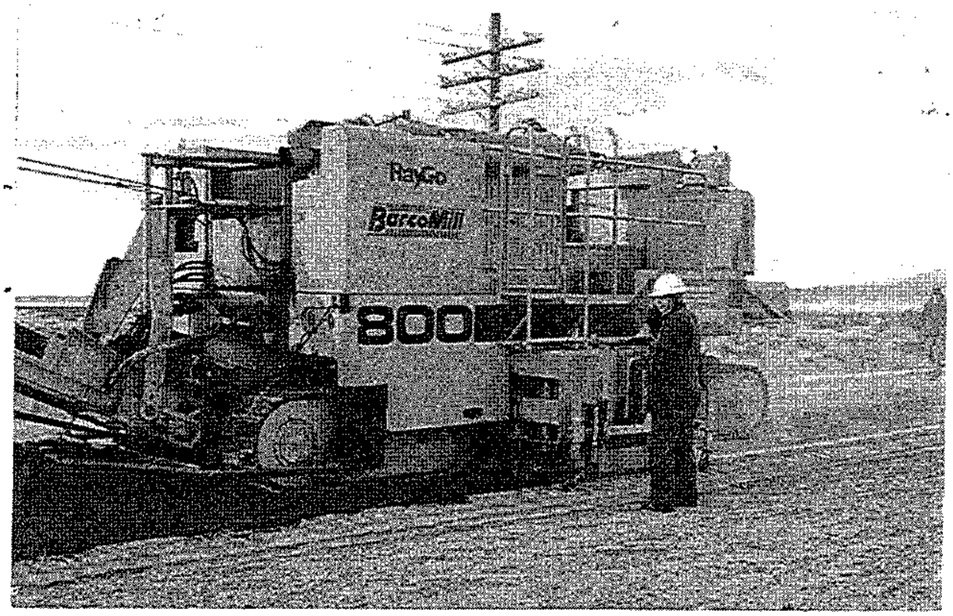
Figure 6

Milling Machine
with Tracks

CMI
Roto Mill



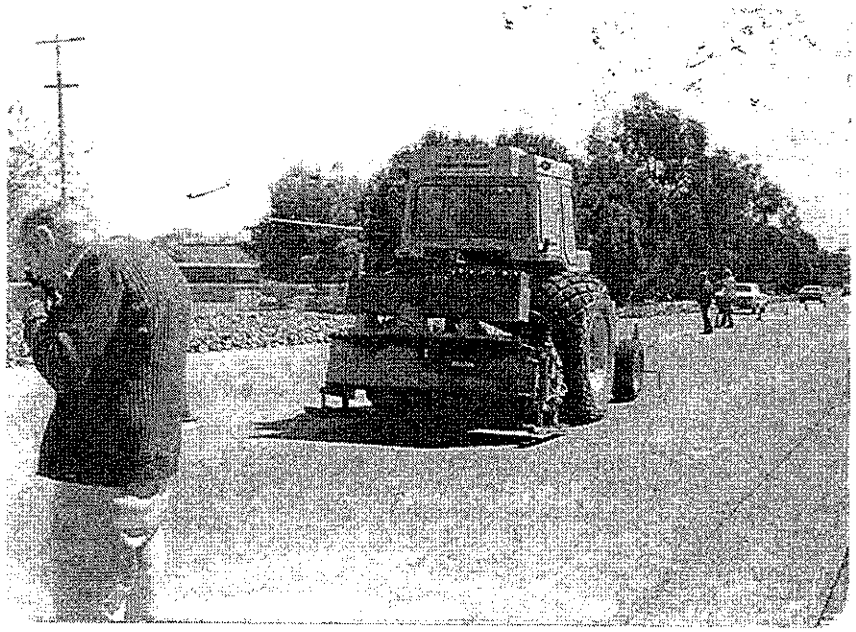
Barber Green
Dynaplane



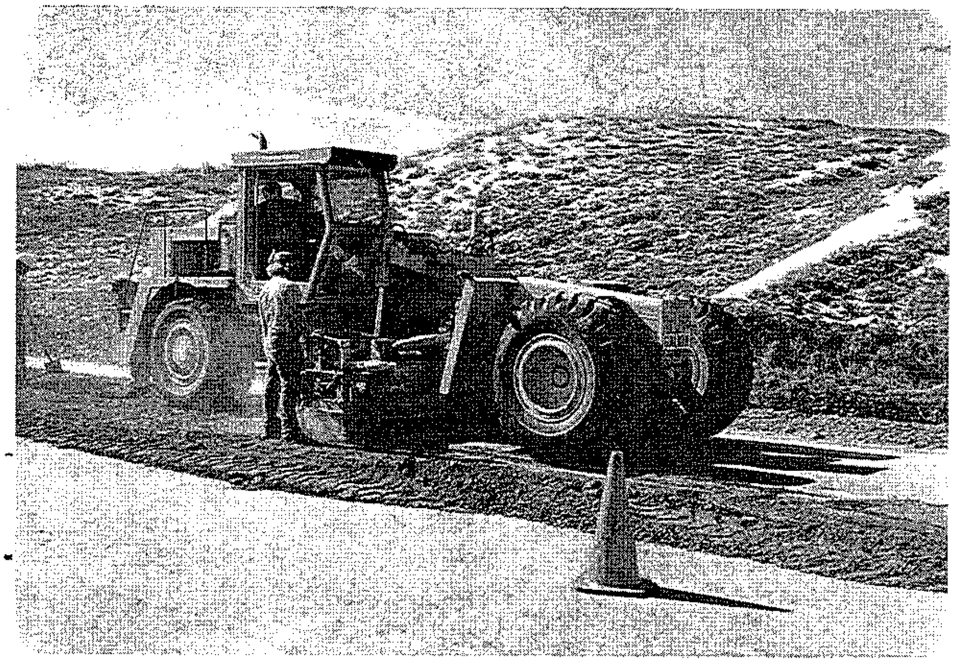
RayGo
BarcoMill

Figure 7

Milling Machines
with Rubber Tires



Cutler
Eager Beaver



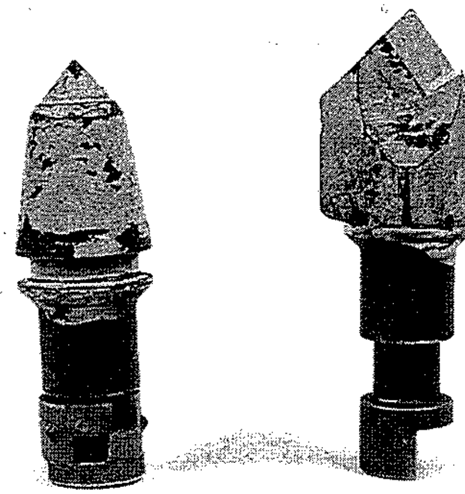
Galion

available (Figure 8); the wedge or chisel, and the conical. The conical tooth (Figure 9) is most effective for milling asphalt concrete and is attached to the mandrel so that it rotates freely due to the cutting friction and, thus, produces an even wear of the shank. The wedge tooth, on the other hand, has a slotted shank which positions the tooth firmly in one position and, thus, considerable wear occurs. The cutting ability of the two teeth appears equal. Both teeth are generally placed on the mandrel in a spiral setting to move material laterally onto a conveyor belt (Figure 10).

The frequency of replacement of the conical tooth (identified in industry as the C-3) will depend on the depth of cut, type of aggregate in the mix, and the speed of operation. The cost per tooth in 1982 was approximately $7.00; however, by 1985 the price had dropped to $2.50. In some areas where the AC contained hard quartz rock, daily replacement of teeth was necessary when a cut 12.5 ft wide and 0.2 ft deep was made. Thus, the desire for industry to provide a more durable cutting tooth has been expressed by the contractors operating these milling machines.

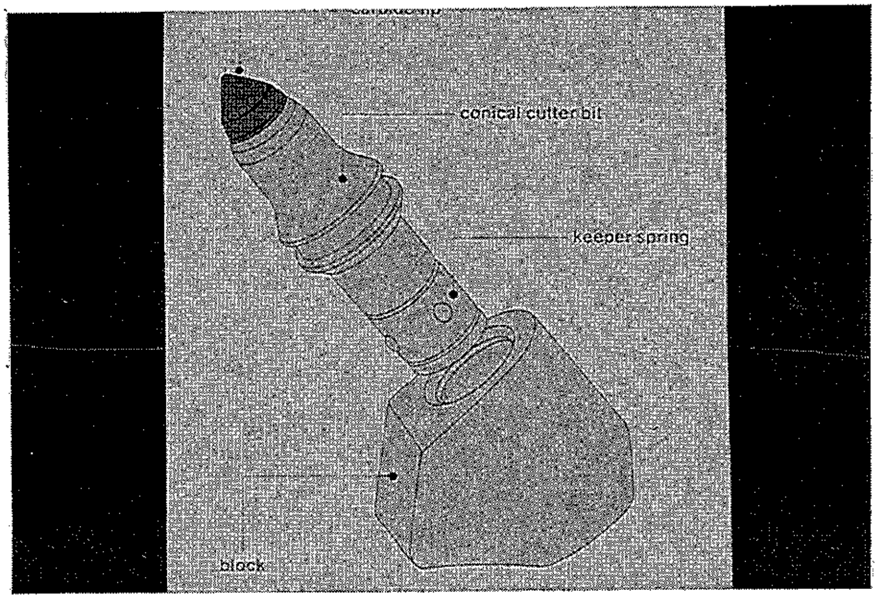
When the milling operation has been properly controlled, the resultant tailings or milled material has been uniform in grading, ranging from about a 1 1/2 inch maximum size to about 20% passing the No. 200 sieve.

The milling machines observed in California have been equipped with either steel tracks or rubber tires. The rubber-tired machines are more maneuverable but, due to tire bounce, often do not provide as uniform or smooth a



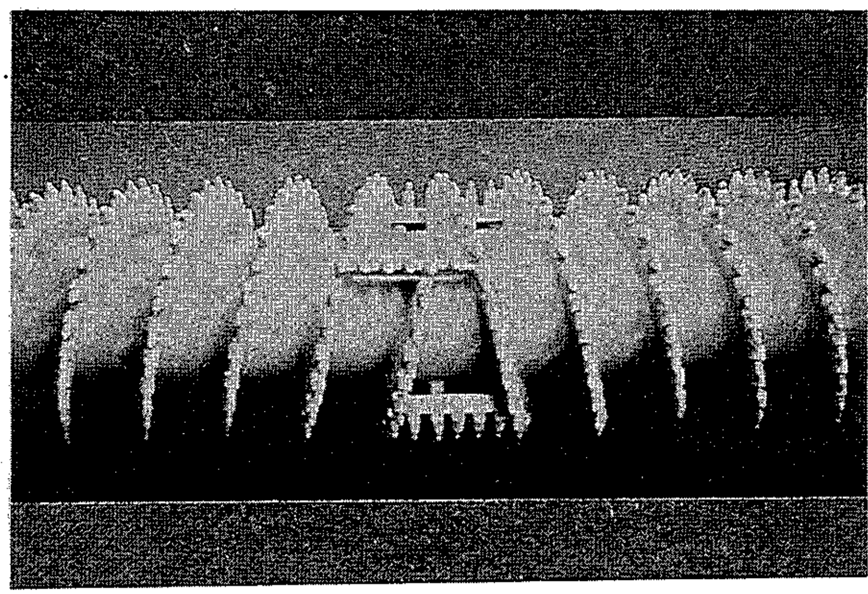
Conical and Wedge Milling Teeth

Figure 8



Conical Tooth (C3)

Figure 9



Spiral Setting for Teeth on the Mandrel

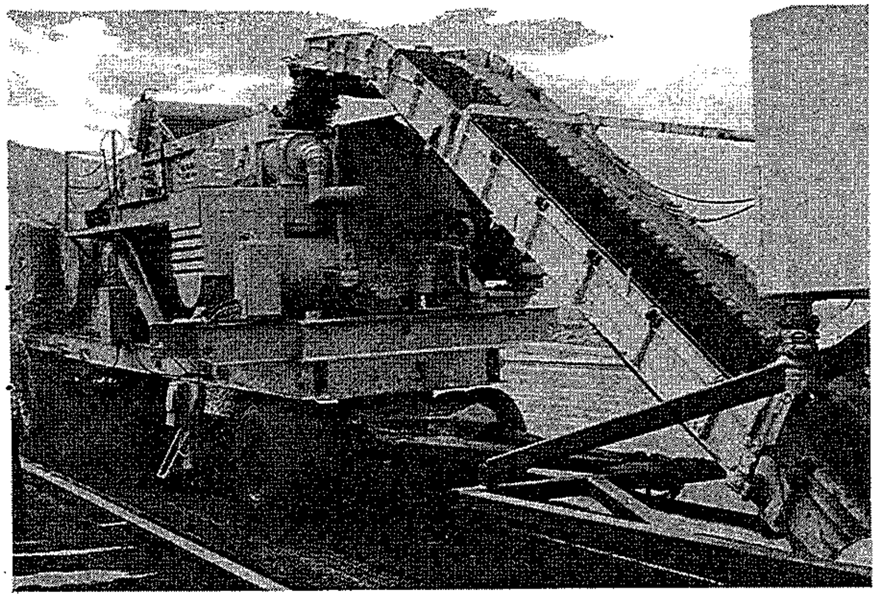
Figure 10

finished grade as the tracked units. When adjacent milling passes are required, the match of elevation between cuts is difficult and often an abrupt break in the grading plane will occur. Thus, the number of parallel passes will affect the cross sectional plane.

C. Sizing of RAP Material

One contractor pioneered and developed a recycling train for sizing and crushing tailings as they are discharged from the milling machine(14-A). This operation consisted of mounting a scalping screen on a flat bed trailer and attaching the trailer to the back of the milling machine (Figure 11). The coarse oversize material then moved across the screen to the rear and dropped into a roll crusher. A collector conveyor then transmitted the combined crushed and fine material to still another machine where it was then volumetrically proportioned and mixed with a recycling agent before being returned to the roadway (Figure 12). The user (represented by the State Inspector) was relieved of the responsibility of continual surveillance to assure that oversize material was not being placed in the windrow (this occurs when alligator cracking is severe, the milling speed is increased, or the teeth become excessively worn). From the producers standpoint, it permitted variations in speed and provided extra milling time with worn teeth, and, thus, a general cost savings could be realized.

Although sizing of the processed salvaged mix is most important for cold in-place recycling, it is also important in the hot recycling process. In the hot recycling method the milled or ripped RAP is transported to the plant site. If the milled material was predominately 2 in. or less, it is stockpiled and ready for use. If the salvaged AC is in

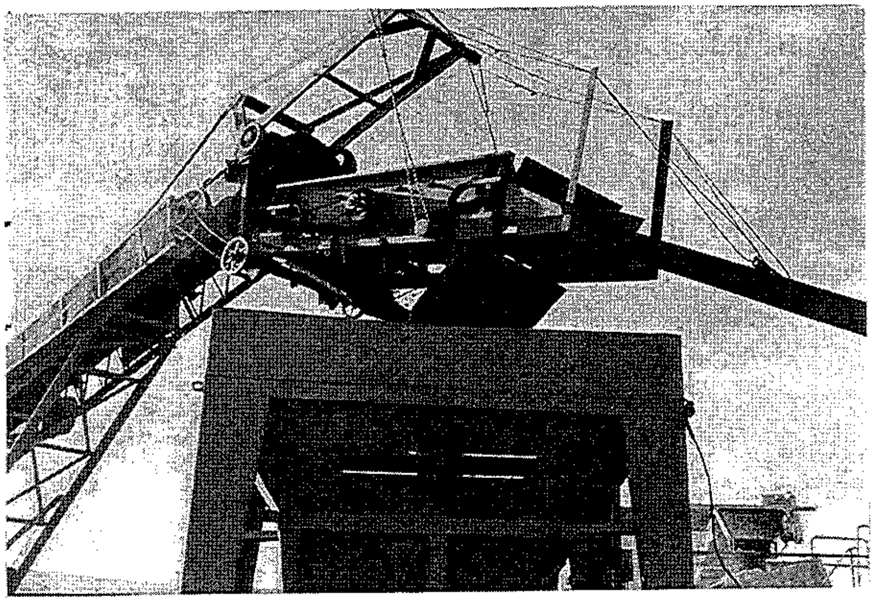


Crushing Oversize
After Milling

Figure 11

Entire Recycling Train

Figure 12



Screen for Removing
Oversize RAP, prior
to heating (Grizzley)

Figure 13

chunk form as a result of ripping, it is crushed and then stockpiled. Stockpiles of the salvaged AC are kept to a height not exceeding 10 ft to avoid consolidation. Salvaged AC being delivered from the stockpile to the plant is subjected to screening (Figure 13) with the oversize (generally 1 1/2 in. max.) either discarded or crushed at a later date.

Maintaining a maximum particle size is important to cold-in-place recycling to permit the softening or recycling agent to cover as much surface as possible. With hot recycling, the salvaged AC is "melted" down and chunks are eliminated; however, pieces greater than 2 in. sometimes will not melt down and may eventually reach the street. This condition creates a problem with placing and provides an imbalanced mix that may result in wet and dry spots on the grade.

The ability to mill or crush the RAP to a consistent gradation suggested the possibility of using the RAP for aggregate base, cement treated base (CTB), shoulder backing or, of course, for hot and cold surface recycling. The use of milled material for aggregate base or cement treated base was given a cursory laboratory review. It was discovered that the milled material (1 1/2 in. max) for the most part was suitable for use as Type II aggregate base, and appeared to compact well under controlled laboratory conditions. Experimental trials in the field resulted in several projects being successfully constructed. One, located near Fort Bragg, is now (1986) about four years old. Another project, located in District 10, was completed about the same period and a third, facilities for a scale and truck inspection on Route 80, was successfully placed near Truckee in 1985 (Contract No. 229004). The

Resident Engineer reported that after compaction, the material was porous and set up like concrete. It was placed about 1.6 ft thick using a small amount of water, compacted with vibratory rollers and it was overlaid with 0.3 ft of asphalt concrete. Various county materials engineers in California have also been recommending the use of RAP as aggregate base.

The use of RAP in CTB also appeared feasible in the lab. Using RAP as CTB aggregate was tried in the field on at least three occasions between 1977 and 1982 and all are performing well. One project was located on Route 26 on the east edge of Stockton (District 10) and was completed in 1977. On this project, a 2.5 mile section between Patterson Avenue and Jack Tone Road was reconstructed by ripping and pulverizing some 10,000 cubic yards of the the old asphalt surface and gravel base (about 50/50), road-mixing this material with 4.0% cement and water, and then recompacting it to form a 10-inch thick cement treated base. Three inches of new asphalt concrete surfacing was then applied. The ADT on the roadway was about 3,800 with 13% trucks. On this project, specifications called for the maximum size of the RAP to be 100% passing the 2 in. and 90% passing 1 1/2 in. It was then mixed to a total depth of 10 in. with the existing base (or underlying) material. The first attempt at pulverizing used a D-8 Caterpillar ripper towing a double-drum sheepsfoot compactor and followed by a Pettibone pulverizer. This method was abandoned after three days. Ripping was slow because of problems in steering the compactor when backing up for long distances to make the necessary repetitive passes to break the AC to 6 in. maximum for the pulverizer. A workable method, used for the rest of the job, was to use the caterpillar ripper without the sheepsfoot compactor.

Cement was spread as a blanket by distributor trucks equipped with continuous weighing devices. The rate of spread was accurate and easily controlled; however, two operating problems developed: (1) the cement blanket concentrated in the furrows, leaving longitudinal lean streaks on the ridges. The mixers did not provide enough transverse mixing action to correct this. Blading the surface flat between the scarifying and cement spreading operations solved the problem; (2) the mixers could not operate closer than 6 in. to a confined edge. After spreading cement, the full depth of cement and aggregate was bladed in from the edge to make it accessible to the mixer and this appeared to solve the second problem.

Two types of mixers were used, a Bros and a Buffalo. Although both were transverse single shaft mixers (about 6 ft wide), the Bros had the water spray mounted behind the shaft and the Buffalo added the water ahead of the shaft. The Buffalo visibly produced the more uniform mixture.

No problem was encountered with compaction. The roadway is performing well to date (1986).

Another Caltrans project involving CTB was completed in 1980 on Route 97 east of Weed (PM 17.1/23.0). The ADT on the roadway was about 5500 with 17% trucks. This roadway was orignally constructed with an aggregate base and dirt shoulders in 1937. Due to increased traffic loadings, it was necessary to rebuild to increase the structural section strength and provide intermittent truck climbing lanes. Cement treated base (CTB) was selected by the designer to supply the necessary strength to rebuild the roadway. The final design called for 0.80 ft of CTB with 0.45 ft asphalt concrete surfacing. The specifications required the use of portion of the old AC pavement as aggregate for the CTB. A CMI Roto-Mill milled the AC surface off to a passing 3/4 in. size. Using a central plant, 70% RAP was blended with 30% virgin aggregate and 5.0% cement to produce the CTB mixture. This was the initial use of 70% RAP as aggregate for CTB (previous projects used about 50% RAP). Compaction was accomplished with a combination of vibratory and nonvibratory steel wheel rollers. However, due to the large percentage of RAP, some compaction problems appeared. It was found that due to the "blend", the CTB could not be compacted to 95% relative density by normal procedures. Two factors that appeared to contribute to this problem were:

1) A wave action developed under the roller regardless of moisture content. Apparently the smooth surface texture which prevented good adhesion and the inconsistent gradation contributed to an absence of interlock between particles.

2) The lab target density, as determined by California Test 312, may be excessive for this type of mixture due to confinement in the mold versus free movement in the field.

In a 1980 non-Caltrans job, the Pacific Gas and Electric Company (PG&E) elected to cement treat a pulverized AC parking lot pavement. Testing of the project area before, during and after the demonstration was commissioned by PG&E. The testing was conducted by Twining Laboratories Inc. of Fresno.

The area was 24 ft wide and 600 ft long. The in-place AC pavement had advanced deterioration in the form of alligator cracking. The structural section consisted of 3 inches of asphalt concrete over 4.5 inches of aggregate base. In the laboratory, crushed asphalt concrete, aggregate base and subgrade materials from the site were proportioned to produce a composite sample for test specimens. Per(31) the PCA Soil-Cement Laboratory Handbook (1971), the composite sample was then tested to meet AASHTO specifications for compressive strength. A series of specimens containing 3, 4, 5 and 7% cement by weight was evaluated. All samples passed the laboratory tests as set forth in the PCA Laboratory Handbook. A cement content of 7.0% was eventually selected.

In the field, Bros equipment was used to pulverize, mix and compact the CTB. No problem was encountered with pulverization. However, mixing and compaction did cause some problems. The cement was not evenly distributed due to the uneven surface, creating a problem with uniformity of mixing. The relative density (96%) was difficult to achieve due to the depth (14 in.). However, after much effort, the specified values were obtained.

The wearing surface consisted of either a 1 in. thick AC overlay or a double chip seal, each placed over half of the project.

Seven-day field cores indicated compressive strengths in both areas of 648 psi. This project is reported to be performing well to date. PG&E estimated a cost saving of 30% by using this approach in lieu of an overlay.

RAP used as shoulder backing has also performed well. No special requirements other than 1 1/2 in. max gradation are required. It compacts well and resists erosion better than virgin aggregate.

In summary, it appears that RAP can be recycled as asphalt-coated aggregate for use as AB, CTB aggregate, or for shoulder backing, but that a more efficient, higher form of recycling can be accomplished wherein the aged asphalt is rejuvenated with the hot, cold or hot-surface procecure.

D. Laboratory Design for Recycled Mixes

1. General

The load-carrying capability of a material is termed its Gravel Factor, or Gf, by Caltrans. For example, (untreated) aggregate subbase is assigned a value of 1.0. Values of 1.4 for cold recycled mixes and 1.9 for hot recycled mixes are now being used for structural section design. These values mean that they have a load carrying potential equal to 1.4 or 1.9 greater than untreated aggregate subbase. They are based on the results of deflection measurements taken of completed projects. The following background information was used in establishing mix design procedures for the hot recycling (Calif. Test 377) and cold recycling (Calif. Test 378) used for these projects.

Because salvaged or reclaimed mixtures usually contain asphalt that has hardened over the years, any added binder must be a soft paving asphalt or an agent that will soften the old asphalt. The agent, when mixed with the aged asphalt, will provide a binder for the recycled mix that is considerably softer than the aged asphalt. This, of course, is desirable if the recycled pavement is to provide extended life with minimal cracking. Recently, hydrocarbon products have been made available that will provide this softening effect on the old asphalt. There are a wide range of softening or rejuvenating agents on the market.

Specifications for these products have been adopted by the Pacific Coast Asphalt User-Producer Group (Table 2). Caltrans feels that recycling agents should be used whenever appropriate to soften or rejuvenate the old asphalt. The amount of softening agent to use will depend on the hardness of the old asphalt recovered from the pavement. It will also be dependent on the stability of the mix containing the additive, whether it be a soft asphalt or a recycling agent. For convenience, Caltrans prefers the recycling agent that arrives on the job for use as binder rather than as an additive to be blended with an asphalt.

California's approach to determining asphalt consistency has been to use viscosity measurements as opposed to penetration measurements. Design policy is such that the final binder in the recycled mix will have an absolute viscosity (AASHTO T202) between 2000 and 8000 poises or generally about 4000. Usually, this can be achieved easily with hot recycling because of the addition of substantial amounts of recycling agent. However, if the old asphalt is relatively soft, (as an old road mix can be) instead of a softening agent, a low viscosity paving asphalt may be required to provide a final viscosity greater than 2000 poise. In the case of cold recycling, the new binder content requirement is relatively low. Because old asphalt is usually quite hard, the lowest viscosity softening agent available today may not provide a recycled asphalt with a viscosity less than 8000 poises. While it is deemed acceptable to design for 8000 poises for cold recycling due to the fact that this material will be overlaid in most cases, hot mixtures intended to serve as surfacing should be designed for 4000 poises to obtain maximum durability.

TABLE 2

Adopted Specifications for
Hot Mix Recycling Agents

TEST	TEST METHOD ASTM	TEST METHOD AASHTO	RA 5 min.	RA 5 max.	RA 25 min.	RA 25 max.	RA 75 min.	RA 75 max.	RA 250 min.	RA 250 max.	RA 500 min.	RA 500 max.
On Orig. Asphalt Viscosity @140°F, cSt	D2170 or 2171	-	200	800	1000	4000	5000	10000	15000	35000	40000	60000
Flash Point COC, °F	D92	-	400	-	425	-	450	-	450	-	450	-
Saturates, wt. %	D2007	-	-	30	-	30	-	30	-	30	-	30
On Residue from RTF-C Oven Test @325°F	D2872[1]	T240										
Viscosity Ratio[2]	-	-	-	3	-	3	-	3	-	3	-	3
RTF-C Oven weight Change, ±, %	D2872	T240	-	4	-	3	-	2	-	2	-	2
Specific Gravity	D 70 or D1298	T228 T227	Report		Report		Report		Report		Report	

1. The use of ASTM D1754 (AASHTO-T179)has not been studied in the context of this specification, however, it may be applicable. In cases of dispute, the reference method shall be ASTM D2872.

2. $\text{Viscosity Ratio} = \frac{\text{RTF-C Viscosity at 140°F, cSt}}{\text{Original Viscosity at 140°F, cSt}}$

2. Recycled Mix Formula

For hot recycle projects, the first decision that must be made is how much virgin aggregate will be in the completed mix. A sudden change in plans concerning the makeup of the formula of the recycled mix after a design has been established will result in construction delays until a new design is completed.

Currently, in California, hot recycling of 100% salvaged AC (RAP) is not permitted due to environmental problems created by burning of the old and/or new binder. To avoid this, the heat transfer system is used, wherein heated virgin aggregate transmits heat to the cold RAP. Mixtures of 60% RAP, 40% virgin or a 50/50 mix have become popular. Generally, the term heat transfer is applied only to a batch plant. The temperature to which the virgin aggregate must be heated to heat the RAP and the effect of this on the plant hardware/components must be taken into account when selecting the amount of virgin aggregate to be included in the recycled AC. The drum plant, however, while incorporating a form of heat transfer, also provides hot gas to heat the salvaged AC. Thus, the recycle formula selection is influenced by such things as the amount of RAP available, environmental and economic considerations, and, in some cases, by the type of plant (batch or drum). For example, a 60/40 mix would be very difficult to produce in a batch plant due to the respective volumes involved and yet a drum plant would have no problem. Also, when mixtures with less than 50% virgin aggregate are used in batch plants equipped with bag houses, the high temperatures required for the aggregate are such that burning of the bags in the bag house has been reported.

3. Gradation of the Milled RAP

In hot mixtures, the "lumps" of RAP melt down so the influence of the milled RAP gradation on target density in the lab is generally nonexistent. However, the gradation of the milled RAP is important in the design of cold mixtures. If the milled or simulated gradation used for mix design in the lab is not similar or identical to the working gradation obtained in the field, the lab target density and recommended new binder content can be in error. The result, of course, can be field problems in 1) obtaining a given density and/or 2) a finished product having a deficiency or excess of new binder and/or air voids.

The need to address the gradation aspect in the design of cold recycled mixtures came about through an analysis of various gradations encountered in the laboratory (Table 3). It became obvious that the design must be based upon actual field gradations. Although project specifications for gradation indicate the maximum size permissible, the amount passing the No. 4 sieve has not been specified by Caltrans because the inclusion of such a specification could add considerably to the cost of milling for reprocessing if limits were not made. An evaluation of various methods of crushing or milling in the field (with only a requirement on the 1 1/2" sieve) revealed that the amount passing the No. 4 sieve was approximately 70% of the passing No. 4 after extraction (i.e., the actual aggregate gradation-Table 4). The freedom to assume a gradation for passing the #4 sieve of 70% (of the extracted grading) offered the engineer the possibility of using about the same gradation in the preliminary lab mix design work as would be obtained subsequently in the field. Thus, in the lab, the RAP samples were crushed accordingly. However, field samples of RAP (after milling) are required for verification. If a

GRADING VS SPECIFIC GRAVITY

SIEVE	EXTRACTION	DESIGN	CONSTRUCTION
	% PASSING	% PASSING	% PASSING
1	-	100	-
3/4	100	92	100
1/2	98	80	80
3/8	90	65	56
4	65	39	$\boxed{26}$
8	48	25	14
200	12	1	-
Sp. Gr.	-	2.33	2.25

TABLE 3

TABLE 4

GRADATION OF SALVAGED AC PRIOR TO EXTRACTION
(Cold Recycling)

Sieve	Bishop (Inyo) A	Bishop (Inyo) B	Bishop (Mono) A	Bishop (Mono) B	Kings Co. A	Kings Co. B	El Dorado Co. A	El Dorado Co. B	Bishop Rte. 178 A	Bishop Rte. 178 B
1 1/2	100				100					
1	98				97	(100)	100	(100)	100	
3/4	94	(100)	100	(100)	94	t98)	98	(99)	91	
1/2	84	(99)	80	(98)	86	(92)	90	(94)	80	(100)
3/8	75	(97)	56	(90)	73	(82)	82	(90)	73	(97)
4	60	(89)	26	(65)	53	(66)	59	(76)	65	(89)
8	41	(76)	14	(48)	41	(53)	42	(64)	46	(78)
16	26	(60)	8	(35)	33	(46)	30	(54)	31	(65)
30	17	(49)	4	(28)	24	(36)	19	(44)	14	(49)
50	12	(36)	2	(21)	13	(23)	12	(36)	3	(35)
100	8	(24)	1	(16)	8	(15)	7	(28)	1	(23)
200	6	(13)	-	(13)	3	(11)	4	(21)	1	(15)
		*		*		*		*		*
by:	RX-75		CMI-750		Hammermill		Cone Crusher		Ray Go	

A = Prior to extraction

B = Extracted gradings

large grading variation exists between lab and the field, a new target density is established using the field gradation and a new mix design is completed.

In <u>hot</u> recycling, the maximum size of the salvaged AC is not as critical as in cold recycling. However, chunks that exceed 2 in. may not melt down and may create problems during placement. Because hot recycled mixtures behave similarly to a conventional hot mix, the same criteria for grading and asphalt content must be observed in the laboratory. Thus, the overall final extracted gradation of the mix must also be considered. The gradation of the virgin aggregate should be selected to provide a combined gradation of new and old aggregate that will satisfy the final mix requirements. For example, the pavement being recycled may be 30 to 40 years old and consist primarily of a fine sand mix. If the traffic volume has increased over the years, a stronger coarser mix should now be provided. This may be accomplished by use of a coarse virgin aggregate gradation which will provide a final gradation that has a "smoother" and/or coarser grading. This need may influence the selection of the amount of virgin aggregate to use.

At the plant, such items as heating of the mix or air pollution versus production goals must be balanced and, thus, an occasional request for a change in formula is made. If field production cannot realistically be adapted to lab design, a new design based on field capabilities should be explored. However, the final mix design must meet the criteria for a conventional hot mix with regard to richness, voids, and stability.

4. Establishing a Lab Maximum Density

a. Cold Recycling

When cold recycling was first attempted, the target density and the method of obtaining a target density were unknown due to 1) an unknown RAP gradation 2) not knowing the amount of premix water and emulsion to use, and 3) not knowing the method of compaction that would be used. Therefore, the first project on Route 395 at Bishop, California, was studied carefully to observe the density that could be achieved with what was considered the best effort possible by the contractor.

The project involved 0.45 ft of recycled mix. Early attempts to place this thickness in one lift resulted in an uneven surface and varying degrees of compaction as measured with the nuclear gage. Subsequent compaction using two approximately equal lifts produced more consistent density and resulted in a smoother surface. It was concluded that considering density, ride quality and rate of curing, cold recycling lift thickness should be confined to a maximum of 0.25 ft. Establishing of this maximum placement thickness increased the possibility of achieving the lab target density in the field.

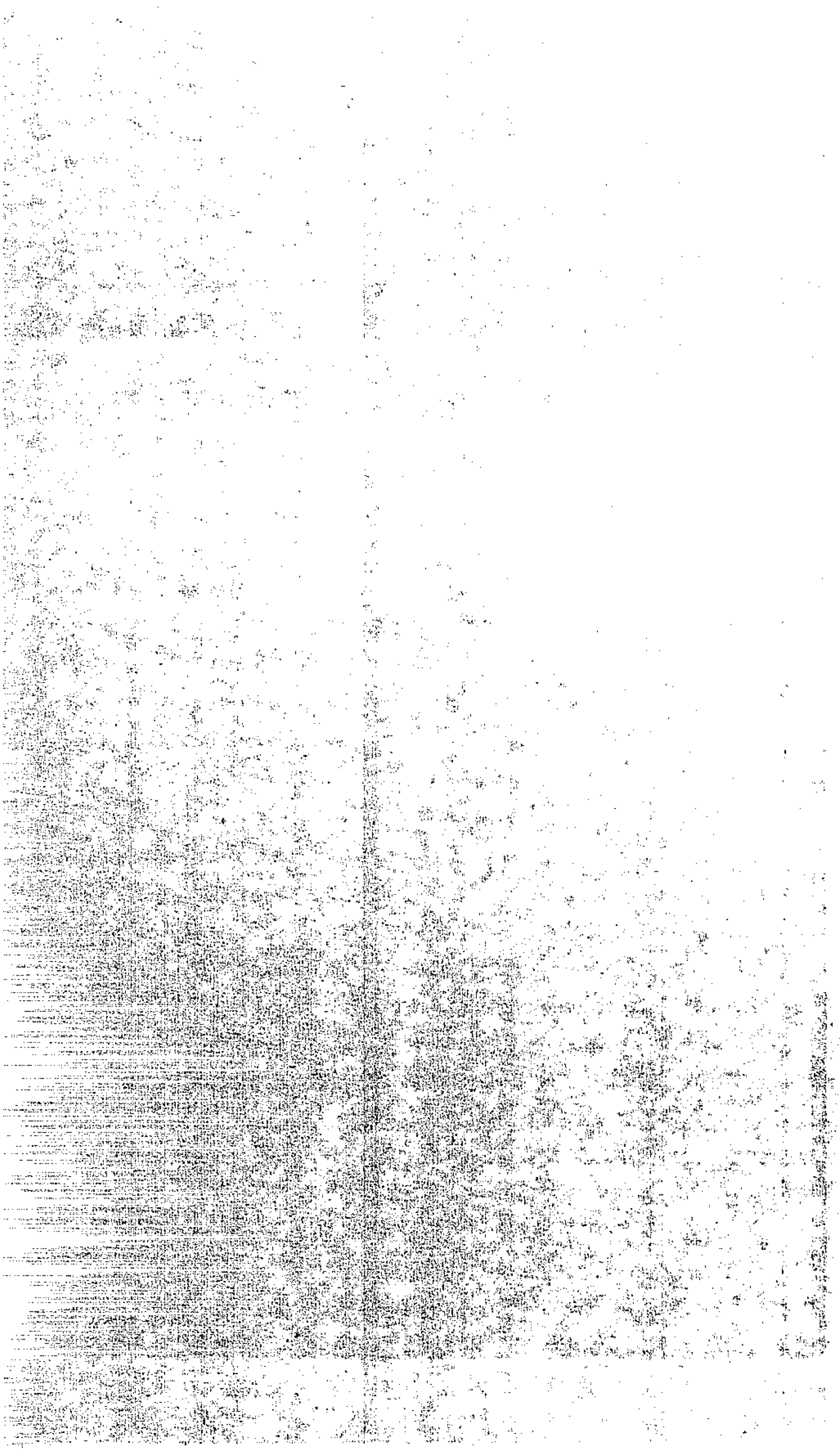
The maximum field density (Table 5 and Figure 14) achieved within 15 days but prior to traffic was recorded. Various laboratory procedures for curing and compaction (with the California kneading compactor - Figure 15) were then used for specimen fabrication and the results compared with the field densities. The method chosen (Method D - Table 6), while not a simulation of field conditions, appeared to provide a good basis for lab design. The rationale for the selection of Method D was as noted in the following discussion:

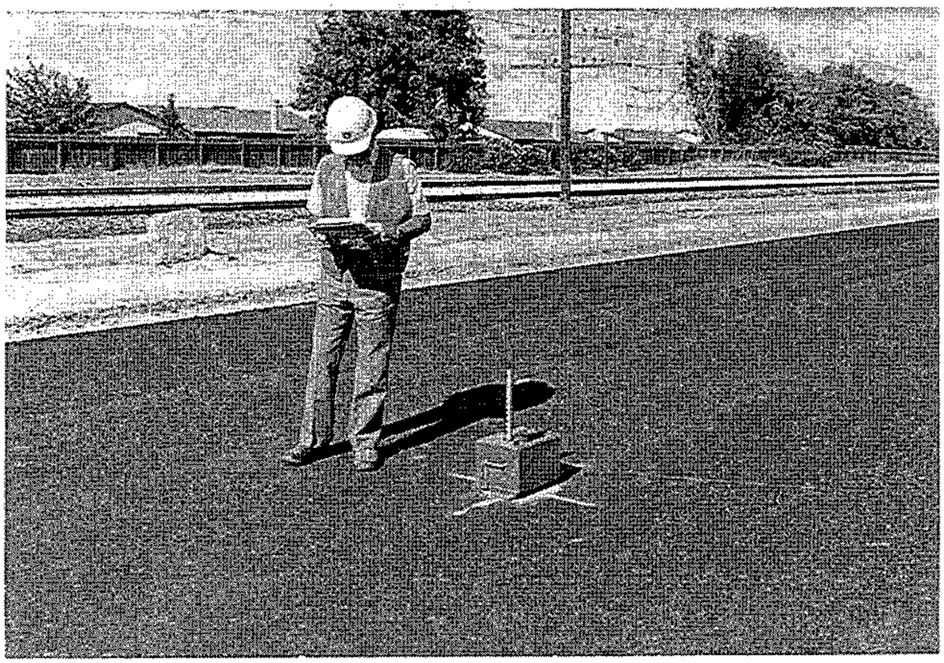
TABLE 5

NUCLEAR GAGE DENSITIES

Project Location	Specific Gravity* High	Specific Gravity* Low	Time After Placement
09-Iny-Rte 395	2.13	2.10	15 days
09-Mono-Rte 395	2.25	2.19	15 days
Diamond Springs (El Dorado Co.)	2.15	2.08	9 days

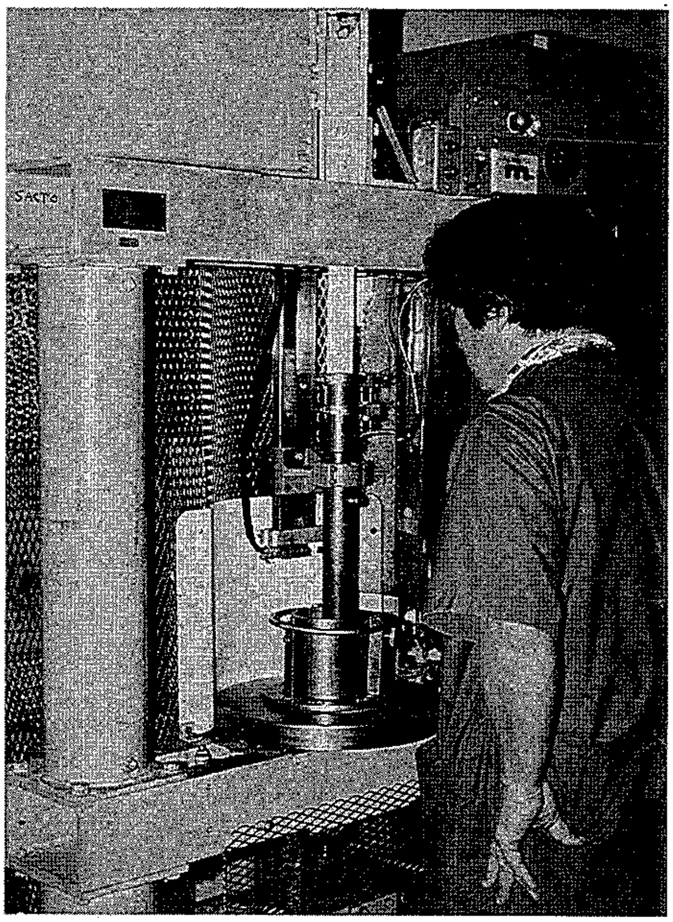
*Determined on the roadway with a nuclear gage.





Testing for Density
With a Nuclear Gage

Figure 14



Preparing Laboratory
Specimen With the
California Kneading
Compactor

Figure 15

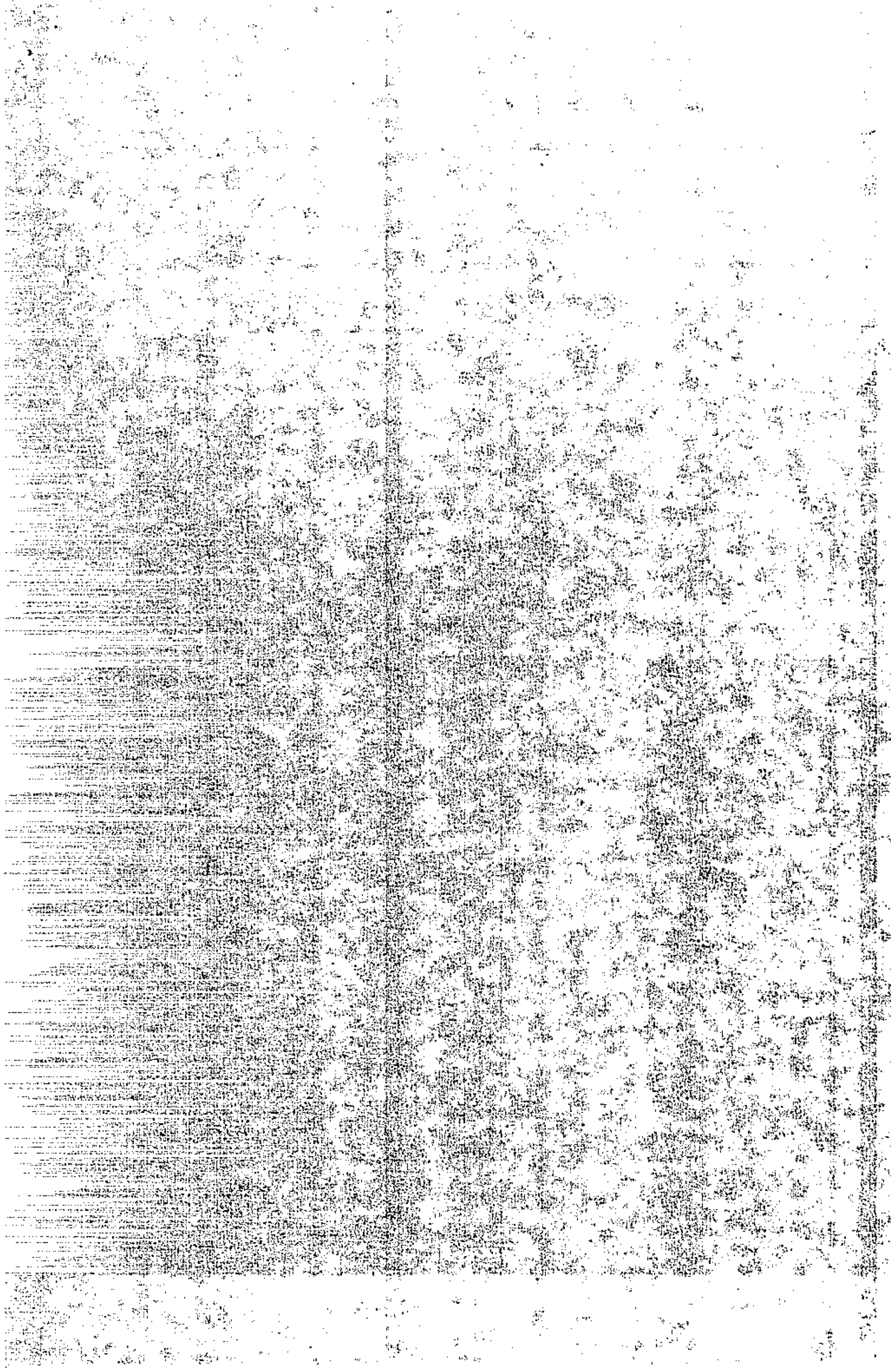


TABLE 6

SELECTION OF LAB FABRICATION

Method	Temperature °F				Specific Gravity and Relative Compaction					
	Cure		Compaction	Test	Project #1		Project #2		Project #3	
	Temp	Hrs			Lab. Sp Gr	* RC	Lab. Sp Gr	* RC	Lab. Sp Gr	* RC
A	-	0	77	77	2.22	95.9	2.32	96.9	2.24	95.9
B	77	15	77	77	2.13	100.0	2.27	99.2	2.13	100.9
C	77	15	140	140	2.21	96.3	2.29	98.2	2.23	96.4
D	140	15	140	140	2.20	96.8	2.32	97.0	2.23	96.4
E	140	15	230	140	2.25	94.7	2.38	94.5	2.31	93.1

*Based on the highest Sp Gr found (see Table 5) in the field, and using the lab Sp Gr as the target density.

Method	Discussion
A	Closest to actual field conditions but with highest moisture content; would be sensitive to change in moisture content due to evaporation. Due to evaporation, difficult to test for stability. Care taken during research (sealed containers - testing within 4 hours of sampling) may be too restrictive for normal operation. Look for another method with less sensitivity to moisture - but provide the same sp gr as this method.
B	Provided the lowest density (in the lab) - use of this method for a target density would produce relative compactions of 100% or more. Not good - field densities could easily exceed these densities with variation in compaction technique.
C	Good correlation with Method A, but curing at 77°F introduces the possibility of insufficient curing or drying for samples having high moisture content.
D	Good correlation with Method A - anticipated reproducibility by drying at 140°F is excellent - testing at 140° means that stability and specific gravity may be obtained with a minimum of time.

Method	Discussion
E	Provides the highest lab density and thus the lowest relative compaction. Not good - the relative compaction in the field would seldom, if ever, reach 96% of lab density if this method were used.

The laboratory procedure for establishing the target density involved two other important features that, unlike temperature or curing period, related directly to the placement. The gradation, previously discussed in paragraph C-2 has considerable influence on the ultimate density whether in the lab or field. The second item, perhaps of lesser importance but still a factor to be considered, is the presence of premix moisture. Premix moisture is defined as that moisture inherent in or added to the recycled mix immediately prior to adding the recycling agent. The advantages of premix moisture are twofold: 1) it promotes coating of the aggregate by the emulsified recycling agents, and 2) it provides lubrication for compaction. The disadvanges are: 1) excess amounts retard compaction, and 2) excess amounts retard curing (Figure 16).

A review of the specific gravity of a cold recycled mix, at target density, indicates the mix would have 2.0 to 3.0% more voids when compacted at 140°F compared to 230°F compaction (Table 6). Since both hot recycled and conventional mixes are compacted at 230°F in the laboratory to establish target density, it is obvious that cold mixtures may well have a honeycomb structure by comparison. Thus, it appears that a protective cover or seal must be applied.

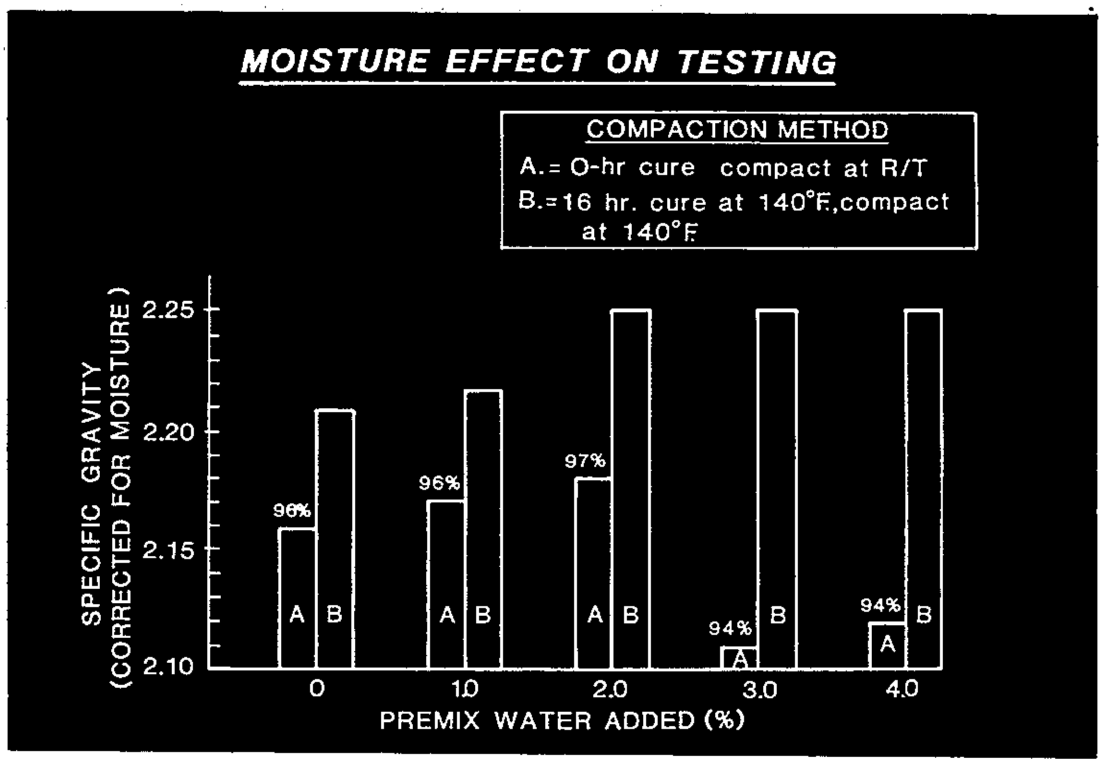
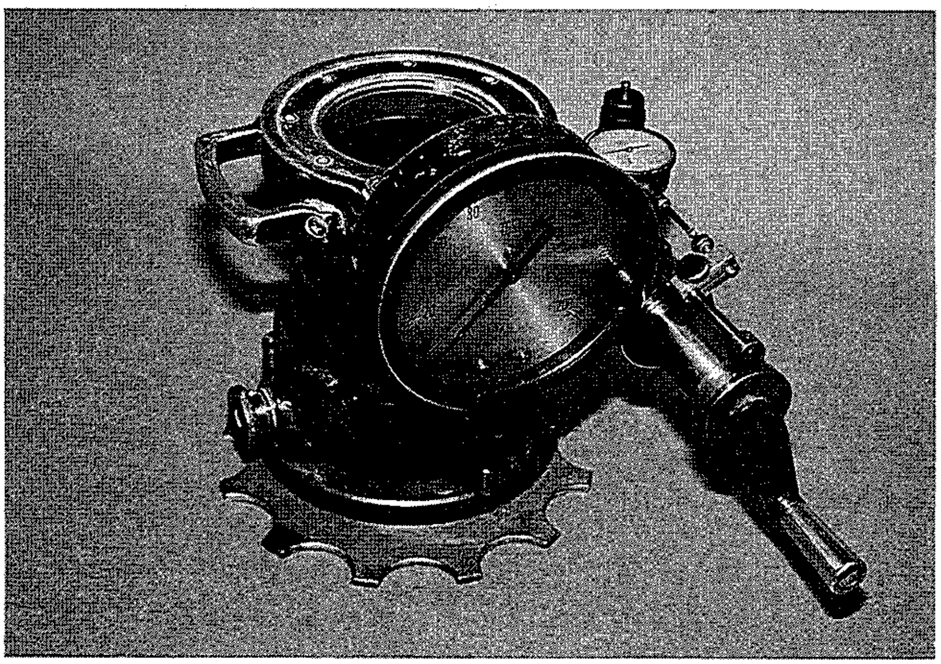


Figure 16



Hveem Stabilometer

Figure 17

b. Hot Recycling

The establishment of a target density for hot recycled mixtures presented no real problems. Due to the fact that this type of mix is heated and virgin aggregate is added, the resultant recycled mix looks and acts much like a conventional AC mixture. Conventional means of compaction are employed both in the lab and in the field. In the laboratory, the California Kneading Compactor was used and the specimens were compacted with 150 blows at 230°F.

5. Stability

While the measured (Hveem) stability of hot recycled mixes posed no problems, the stabilities of cold recycled mixtures that were measured present the designer with somewhat of a dilemma. Stability of conventional asphaltic mixtures (defined as the ability to resist plastic deformation under vertical load) is measured using the California (Hveem) stabilometer (Figure 17). An emperical relationship for stability is used which provides a scale ranging from 0 to 100. On this scale, liquid is portrayed as being equal to 0 and a solid as being equal to 100. Stabilometer values of 30 plus have been specified for conventional hot mixtures for many years and performance records have provided confidence in this requirement. Values less than thirty have been designated as potential problem mixtures in terms of displacement under load based on the performance records of several projects.

Various mix properties will affect stability. For example, the amount of voids in the mix, aggregate angularity, moisture and/or asphalt content may have a direct effect. Excess voids can produce lower stability values due to a lack of interparticle keying. Conversely, a deficiency of voids may create a critical mix with a low stabilometer value due to over lubrication (caused by an excess of asphalt or moisture).

Because stabilometer value is a good indicator of roadway performance, it was tentatively decided to select minimum values of 30 for cold recycled mixtures placed in the roadway and 20 for mixtures placed in the shoulder areas. The decision to use the stabilometer test as a design tool for cold recycled mixes was based on the fact that an excess amount of new binder and/or improper mix gradation will cause a drop in stabilometer value. Thus, to avoid a tendency to over-asphalt (cold mixtures, due to the use of emulsions, have a tendency to look dry) and create an unstable mixture, stability measurements were obtained.

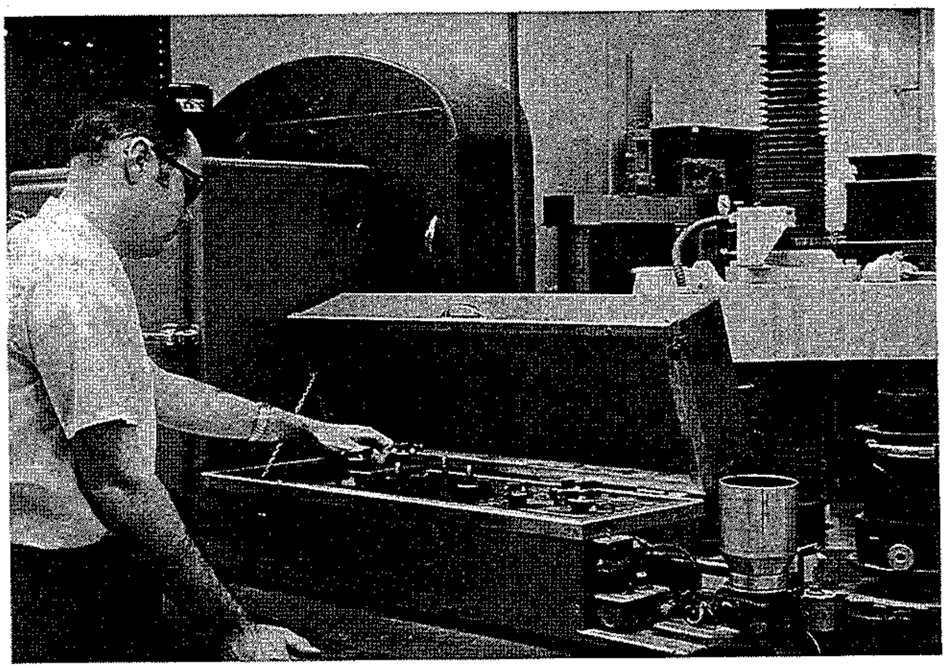
Stabilometer measurements of mix with optimum binder content and a good angular aggregate if determined immediately after mixing and compacting at room temperature (using 500 psi and kneading compaction), generally range from 10 to 15. After curing (removing all moisture) and compacting at 140°F, the stabilometer value of the mix will range from 15 to 35. The same mixture, when cured and then compacted at 230°F, will have stabilometer values in the range of 35 to 45. Thus, even though the basic ingrediants for good stability, optimum asphalt content, proper aggregate gradation, and good aggregate angularity, do not change, the stability values denoting satisfactory mix do change (decrease) when the cooler mixing, curing, and testing temperatures considered appropriate for cold recycled mixes are used.

6. Cohesion

Cohesion (California Test 306) was measured using the California cohesiometer (Figure 18). Cohesion (defined as a measure of tensile strength) of both hot and cold recycled mixture ranges from 200 to 300 at target density. Cohesion in the California mix design criteria, however, has never been a specific consideration due to variation in values caused by particle orientation within the mix; thus, although tensile strength comparable to a conventional hot mixture is indicated, no specific requirement has been established.

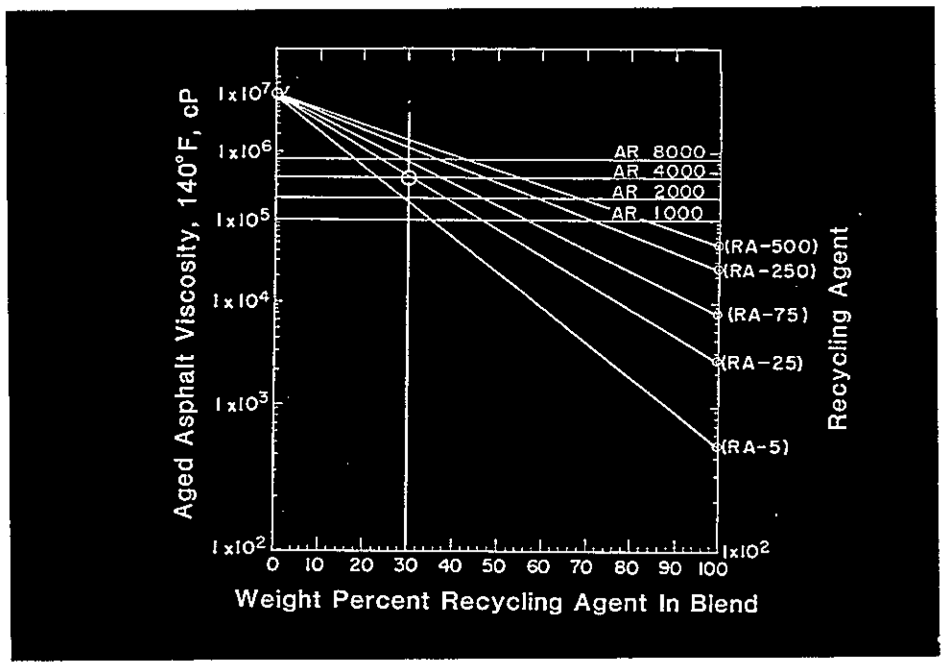
7. Grade and Amount of Binder

Because RAP will contain asphalt that has hardened, any added binder should be capable, when mixed with the aged asphalt, of providing a binder for the recycled mix that is considerably softer than the aged asphalt. In searching for a design procedure that would provide a binder that would satisfy the asphalt demand of the entire mix and soften the old binder at the same time, the theoretical design procedure described in Reference 19 was tried. With this procedure, the amount of binder to use is based upon a theoretical surface area which is, of course, dependent on the gradation. With the use of a nomograph, the theoretical final viscosity could also be determined for different amounts and grades of softening agent (Figure 19). With some modification, this procedure was used as a basis for the development of the test methods for recycled mixtures (California Test 377 for hot recycling and California Test 378 for cold recycling).



California Cohesiometer

Figure 18



Design Nomograph

Figure 19

Basically, the test consists of determining the approximate asphalt demand, then selecting the appropriate grade of recycling agent to provide a final asphalt consistency that meets the design target. The target 4000 poise viscosity was selected because most of the new AC mixes placed in California are using this grade (or viscosity) of asphalt. Subsequent TransLab tests revealed a fair correlation (Table 7) between the design and the final (actual) viscosity.

The design can be checked with a fair degree of confidence via the Abson recovery test (California Test 380) on the final hot recycled mixture. This is due to the melting of the old asphalt during processing and the good blending of the hot old asphalt with the hot softening agent. However, with cold recycling the verification of the softening effect on the old asphalt cannot readily be determined via Abson recovery. In the Abson recovery process, the entire mix is exposed to solvents to remove the asphalt for testing. Thus, an ideal but false blending of the old asphalt and softening agent occurs. Under actual conditions, the agent softens the old asphalt film, but at a slow rate. The degree of softening and/or the amount and time involved are dependent on 1) the grade of recycling agent, 2) the amount of recycling agent, and 3) the mean ambient temperature. Work to provide a method for determining the effect of softening agents on cold recycled mixtures is continuing. Some preliminary data indicate that the Resilent Modulus test (M_R)(20) has some potential (Table 8).

TABLE 7
ABSON RECOVERY DATA

*RAP/Agg.

Location	Date: Placed	Date: Cored & Tested	Theo. Design Visc. @140°F (Poises)	Viscosity (Poises) 140°F	Viscosity (Poises) 275°F	Pen. (77°F)	S.P. (°F)	Duct. (cm)	Mix Type	Recy. Formula *	Recy. Agent Grade
2-Sis-5	8/79	8/79	--	72,000	2,064	23	151	15	RAP	--	--
PM 20.5/25.6		8/79	4000	13,341	636	40	138	67	R/C	70/30	RA75
Weed		6/86	4000	20,700	906	30	143	100+	R/C	70/30	RA75
(Hot Recycle)		8/79	4000	11,094	712	32	135	100	R/C	50/50	AR2000
		6/86	4000	19,900	1,000	24	142	82	R/C	50/50	AR2000
3-Nev-80	10/78	10/78	--	300,000	3,500	6	180	4	RAP	--	--
PM 41.0/65.5		10/78	4000	9.272	736	35	136	100+	R/C	50/50	AR2000
Gold Run		6/86	4000	16,825	867	30	144	70	R/C	50/50	AR2000
(Hot Recycle)											
8-SBd-15	10/80	10/80	--	69,000	11,000	10	155	6	RAP	--	--
PM 53.8/71.1		10/80	4000	3,138	309	53	124	100+	R/C	50/50	RA75
Barstow		10/82	4000	4,001	342	42	129	100+	R/C	50/50	RA75
(Hot Recycle)		5/86	4000	25,950	797	17	147	10	R/C	50/50	RA75
8-SBd-15	10/83	10/83	--	28,000	745	14	145	37	RAP	--	--
PM 139.0/162.7		10/83	4000	6,748	642	28	132	100+	R/C	50/50	AR1000
Baker		5/86	4000	12,130	587	25	139	56	R/C	50/50	AR0000
(Hot Recycle)											
8-SBd-395	6/82	6/82	--	200,000	1,900	15	162	6	RAP	--	--
PM 17.8/42.7		6/82	4000	2,702	313	55	122	100+	R/C	All RAP	RA25
Adelanto		11/83	4000	26,623	772	19	144	75	R/C	All RAP	RA25
(Cold Recycle)		5/86	4000	70,316	1,152	16	152	8	R/C	All RAP	RA25
9-Iny-395	10/79	10/79	--	57,000	948	11	152	8	RAP	All RAP	--
PM 110.8/115.0		10/79	4000	6,594	388	44	128	100+	R/C	All RAP	RA25
Bishop		4/86	4000	9,830	557	30	134	100+	R/C	All RAP	RA25
(Cold Recycle)											

TABLE 8
M_r Date (AVERAGES) ($x10^5$)
(3 Tests)

Location	Date		Orig. Data (Lab Comp)	FIELD DATA					
	Placed	Tested		Core	Recompact. 140°F	Recompact. 230°F	Mix Type	Recy. Formula	Recy. Agent
2-Sis-5		8/79	6.10		--		R/C	70/30	RA75
PM 20.5/25.6		8/79		5.36	--	6.54	R/C	70/30	RA75
Weed	8/79	6/86		3.61	--	3.27	R/C	70/30	RA75
(Hot Recycle)		8/79	8.67		--		R/C	50/50	AR2000
		6/86		3.69	--	3.06	R/C	50/50	AR2000
3-Nev-80		10/78	6.13		--		R/C	50/50	AR2000
PM 41.0/65.5	10/78	6/86		2.63	--	3.98	R/C	50/50	AR2000
Gold Run									
(Hot Recycle)									
8-SBd-15		10/80	3.00		--		R/C	50/50	RA75
PM 53.8/71.1	10/80	10/82		2.10	--	2.90	R/C	50/50	RA75
Barstow		6/86		3.20	--	3.34	R/C	50/50	RA75
(Hot Recycle)									
8-SBd-15		10/83	8.80		--		R/C	50/50	AR2000
PM 139.0/162.7	10/83	10/83		6.20	--	7.38	R/C	50/50	AR2000
Baker		6/86		2.90	--	2.96	R/C	50/50	AR2000
(Hot Recycle)									
8-SBd-395		6/82	6.39		--		R/C	All RAP	ERA25
PM 17.8/42.7	6/82	11/82		4.92	--	6.78	R/C	All RAP	ERA25
Adelanto		6/86		3.00	3.32	4.56	R/C	All RAP	ERA25
(Cold Recycle)									
9-Iny-395		10/79	3.14		--		R/C	All RAP	ERA25
PM 110.8/115.0	10/79	5/82		3.40	3.27	5.06	R/C	All RAP	ERA25
Bishop		6/86			--			All RAP	ERA25
(Cold Recycle)									

At present, a cold recycled mix is designed as if total blending of old asphalt and softening agent occurs immediately. With the binder, aside from the amount and grade, the controlling feature in need of attention is the theoretical viscosity of the blend of old asphalt and agent. When test analyses indicate that a given amount and grade of recycling agent are required to rejuvenate the old asphalt, that combination is tested. If the mix is not correct, the amount of recycling agent is adjusted. In doing so, the basic theoretical viscosity of the recycled binder will be affected. Therefore, to approach a desired "end" viscosity for the recycled binder, a trade off is often effected involving selection of another grade of recycling agent. Field variation in the amount and viscosity of the asphalt in the RAP, due to the presence of maintenance blankets and/or patches and the age variations of these ingredients, may require adjustments in the binder content. Switching grades of binder to correct for this is impractical; therefore, a range of viscosity must be accepted. To minimize this problem, extensive and judicious sampling of the pavement proposed for recycling is most important. Areas requiring different quantities of agent may be delineated in the street for cold recycling. For hot recycling, separate stockpiles may be established at the plant to facilitate various mix designs if the RAP is highly variable. If the RAP variation is considered excessive, recycling should be discouraged.

E. Mixing and Placing of Recycled Mixes

1. Cold Recycling

RAP, after milling, was generally deposited in a windrow in the center of the lane. It then was mixed with a new binder (emulsified recycling agent), relaid and compacted in one lift. As discussed earlier, the depth of cold recycling should be confined to 0.25 ft. Replacing this amount of material in the grade will result (due to bulking caused by premix moisture and new binder) in an uncompacted lift of approximately 0.45 ft. Obviously, deeper cuts will result in thicker lifts which provide windrows that are too large in volume to effectively mix unless divided into smaller volumes. Also, in one-lift compaction, the thicker the lift the more elusive the target density becomes. It is possible, of course, to mill deep and then place the recycled material in two or more lifts. On one such attempt (Route 101 - 1982), the pavement was milled in two passes, each about 0.2 ft. After the first pass, the milled material was mixed (recycled) and then bladed to the side while the second cut was made. The second cut was following day, the recycled mix from the first cut was then bladed back on top of the recycled mix from the second cut and then compacted. The new emulsion in the material from the first cut had broken and, as a result, the mix was crusty and extremely difficult to compact (although compaction requirements were ultimately satisfied). Thus, to date this procedure has not been perfected.

Various methods and equipment have been used for mixing, placing and compaction. Some of the equipment observed included:

a. Mixing and Placing

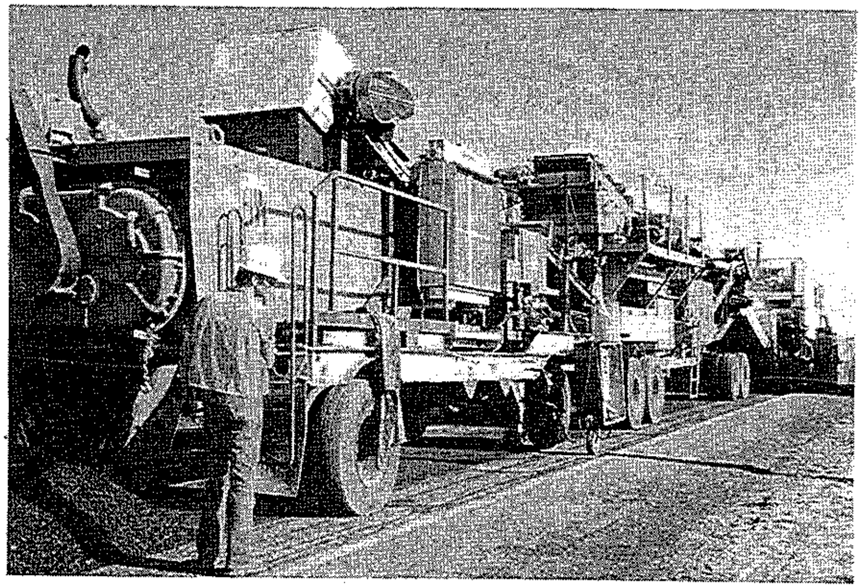
(A1) Midland Paver (Figure 20) - This machine is self-propelled and resembles a conventional paving machine in appearance. However, it is also equipped with a self-contained supply of binder, and a pug mill for mixing. With the use of a Kocal attachment, it can pick up windrowed material, add binder, mix and place at rates as high as 30 feet per minute.

(A2) The Valentine Mixer (Figure 21) - This unit is not self-propelled. It is the last unit attached to a recycling train that consists of 1) a cold milling machine (Roto Mill), 2) a sizing machine, and 3) the mixing unit. The unit is basically a converted CTB plant that is fed continuously via a conveyor belt from the sizing machine. It is equipped with its own supply of binder and has a twin-shaft pug mill. To provide interlocks with flow of aggregate and binder, it uses Ramsey weight sensors on the belts. After mixing, the recycled mix is deposited in a windrow where it is then picked up with a conventional paving machine (using a Kocal attachment) and placed in the same manner as a hot mix.

A3) The Gardner Mixer (Figure 22) - This self-propelled unit straddles a windrow of RAP. It adds new binder and, with the use of an enclosed mixing chamber, mixes and places the recycled mix in a windrow. This unit must have an exterior supply of binder to operate. Placement is done with the blade of a motor grader or with a conventional paving machine.

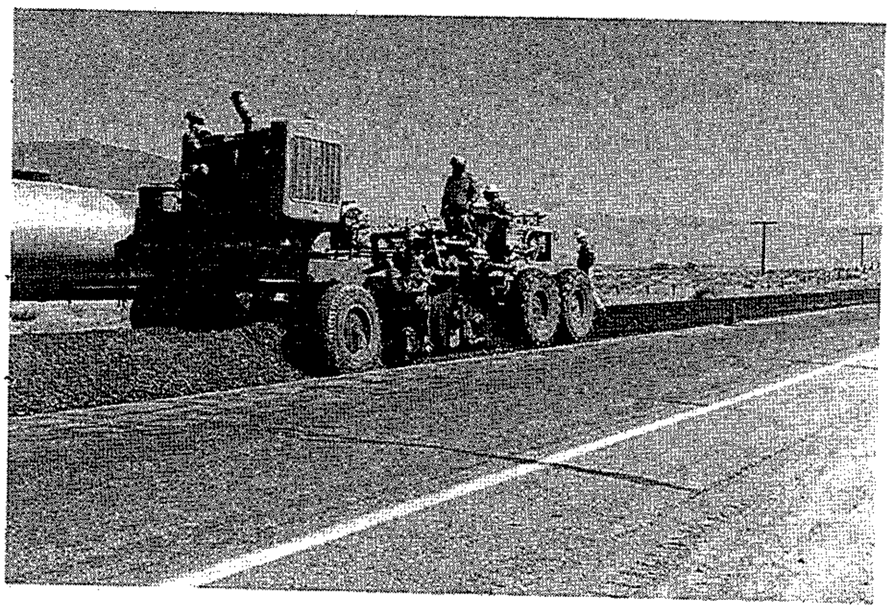
Midland Paver

Figure 20



The Valentine Recycle Train

Figure 21



The Gardner Mixer

Figure 22

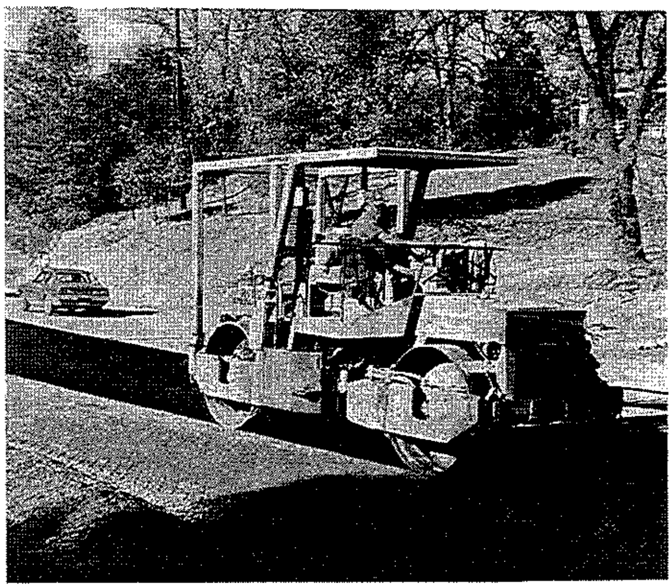
A4) The Seaman Mixer (Figure 23) - This unit is not self-propelled, but is pulled or drawn over a windrow after the windrow has been sprayed with new binder. With the use of a cross shaft pug mill, it then mixes and leaves the recycled mix in a windrow about 4 ft wide behind the unit. Placement is done with either the blade of a moter-grader, or a paving machine.

b. Compaction Equipment

B1) Conventional 10 and 12-ton steel wheel vibratory rollers (Figure 24) and large 25 to 35 ton pneumatic rollers (Figure 25) have been used for compaction. As mentioned earlier, the exact sequence or combination of rolling that will provide the best compactive effort is yet to be established. So far, about 87% of laboratory target density has been provided by the construction operation. The density appears to increase as much as 10% after 3 or 4 days of traffic. Undoubtedly, the curing of the mix as the water evaporates is enabling additional compaction to be realized. The value of vibratory rolling with this type of mix (emulsion) has been accepted by some and rejected by others. Some claim that on breakdown, use of the vibratory mode creates a disturbance due to moisture lubrication in the mix that works to retard compaction. Others have not experienced this problem. On one project, a large pneumatic roller was used for breakdown and values as high as 92% relative compaction were immediately realized. Thus, breakdown or initial compaction appears greatly dependent on the existing moisture content as well as the equipment used. Again, to date no specific compaction method or sequence has been adopted by Caltrans.

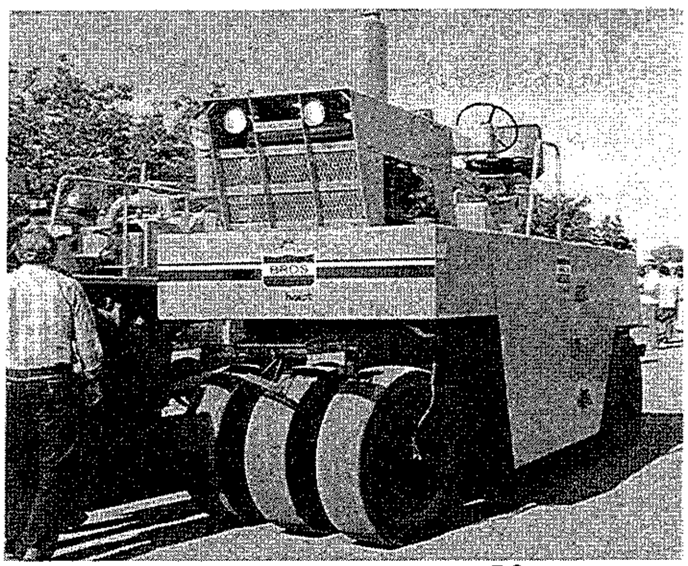
Seaman Mixer

Figure 23



Dynapac
Vibratory Roller

Figure 24



Bros Pneumatic Roller

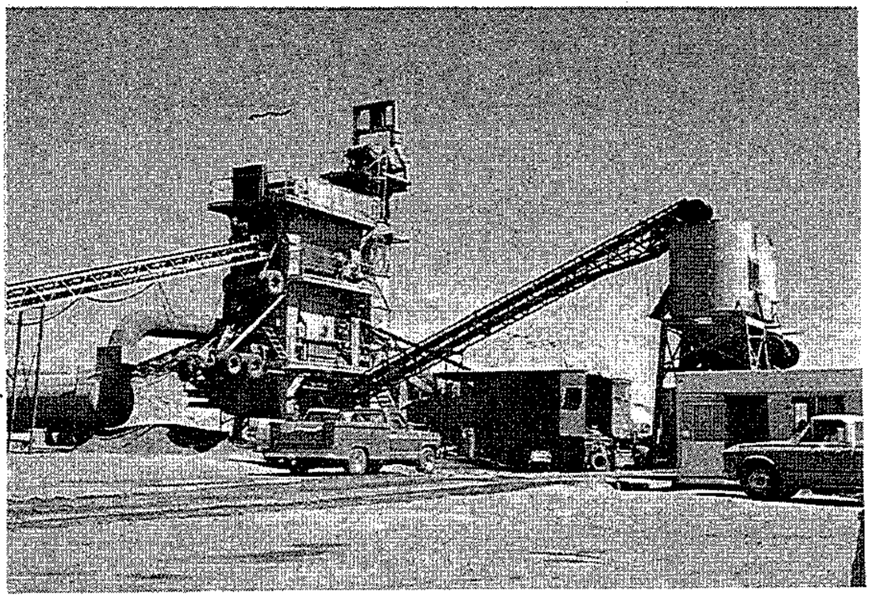
Figure 25

2. Hot Recycling

Hot recycling has been accomplished using either a converted batch plant or a drier-drum (Figures 26 and 27). The batch plant conversion simply consists of an additional conveyor that transports the RAP into the pug mill of the plant. Superheated virgin aggregate is mixed with the cold RAP to obtain the necessary heating of the RAP. After a few seconds of mixing, hot new binder is added. After additional mixing, the recycled mix is discharged into trucks for transport to the "street". Most recycling in California by the drier-drum has used the CMI unit; however, the Barber Green, Astec and others have also been used. With the CMI units, both the older converted and the newer units, the salvaged AC is placed into the center of the drum and hot new binder is added 5 or 6 feet further down the drum (toward the discharge gate). In one converted unit, a metal disc was welded to the drum about 10 feet from the burner end of the drum to prevent the flame from burning the RAP and/or new binder (Gold Run and Weed projects). The newer CMI units, however, relied on lifters within the drum to provide a curtain or veil of virgin aggregate (at the burner end) to provide this protection.

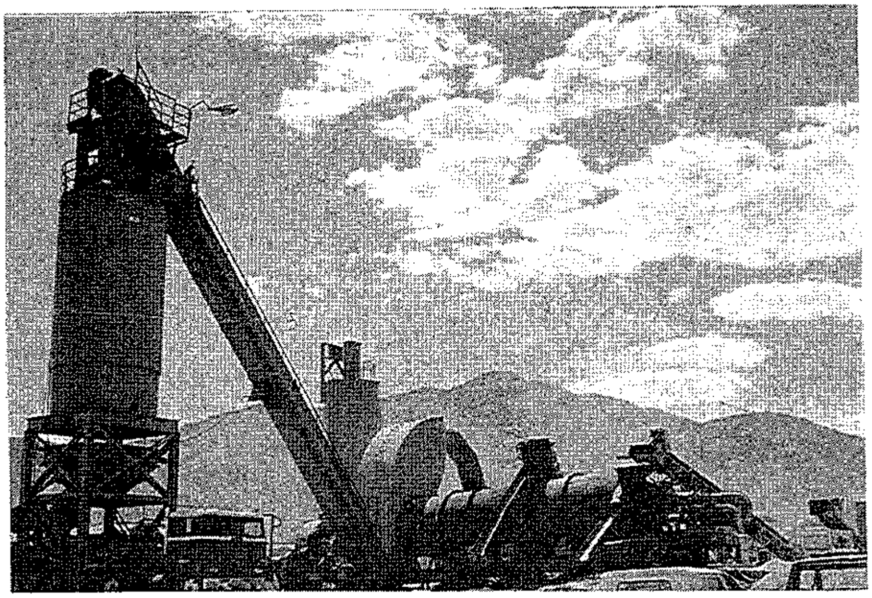
It appeared, to plant inspectors, that the metal baffle was the more effective of the two approaches. One new CMI unit relying on a veil of new aggregate was cited three times on one project for violation of the California clean air standards.

Recycled mix formulas (RAP/virgin agg.) used were the 35/65, 50/50, 60/40 and the 70/30. Except for the Blythe projects and for the 70/30 mix, all of these combinations



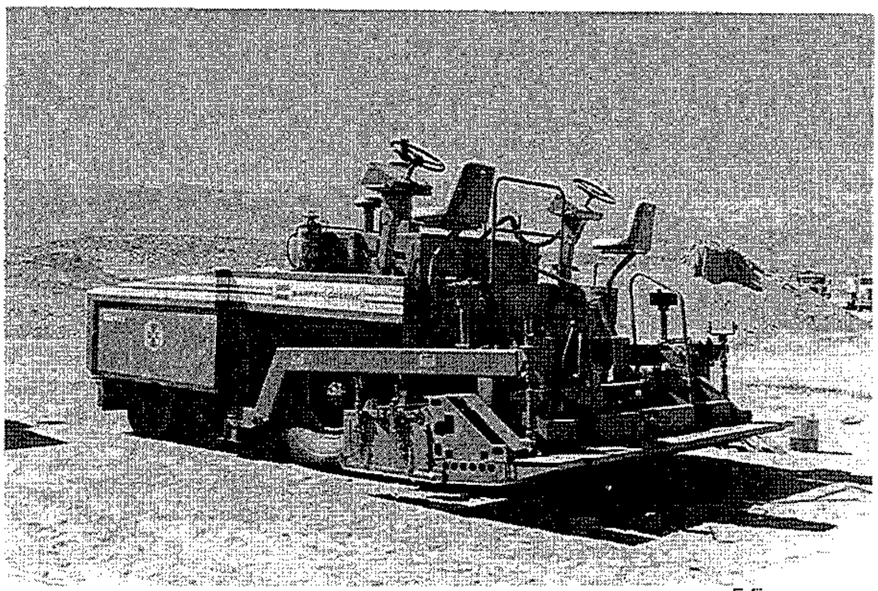
Batch Plant Converted
for Recycling.
Note: Conveyor on the
left for delivery of RAP

Figure 26



Drier Drum Converted
for Recycling.
Note: Conveyor in center
of drum for delivery
of RAP.

Figure 27



Conventional AC
Paving Machine

Figure 28

mixed and performed well. The 70/30 mix that was used on the Gold Run and Weed projects did not appear well coated upon delivery to the street and premature cracking was observed. The 70/30 and 60/40 mixes were used only in a drier drum. Others reporting on recycling have cited problems with a batch plant if a mix containing 50% or more RAP is used. The only mix prepared in California using a batch plant was the 35/65 mix and no problems were experienced. Caltrans has suggested that a drier drum be used if mixtures containing 50% or more RAP are proposed. Eventually, mixtures with with a maximum of 15% RAP are contemplated with the RAP being considered as new aggregate. These mixtures could be permitted in any plant and would not require the design criteria for recycled mixtures. Mixtures with over 15% RAP would require a recycled mix design, however.

Hot recycled mixtures have been placed at 250°F to 300°F using conventional paving equipment (Figure 28) compared to conventional AC. No difficulty in placing has been experienced.

F. Hot Plant Control - Using a Vacuum Extractor vs a Nuclear Asphalt Content Gage

In order to control the hot recycled mix production at the plant site, a method of quickly measuring asphalt content is required. For the most part, the Vacuum Extraction Test (California Test 360) was employed. Extraction tests were performed on the RAP sampled immediately prior to mixing, and also on the final recycled mix. The difference in recorded asphalt quantities indicated the amount of recycling agent added. This method, although accurate and relatively fast (about 1.5 hours per test), was still considered too slow for effective plant control. As a consequence, it was decided to try the nuclear asphalt content gage as a means to evaluate the asphalt content of recycled mixtures. The result was a test procedure(26) that was workable in the field (Table 9). Subsequently, it was decided to add a section to California Test 379(26) for determining asphalt content of recycled mixes. Although occasional differences exceeding 0.5% between test methods were noted, all of these samples were obtained in the field and such variables as sampling and quartering are reflected in the test results. Most of the data showed the two test methods studied 310 & 379B) were within ± 0.3% of each other. It was observed in the field that as many as 10 tests per hour could be performed after the gage was calibrated. This provides a tremendous boost in the control of plant operations, especially during the first few hours while establishing plant operation stability.

G. Performance of Recycled Mixes - Tables 10, 11, 11A and 11B

1. Hot Recycled Mixes

Three projects recycled by the hot-central-plant process were singled out for a performance evaluation covering a four-year period. Each project had a conventional asphaltic mix or control section to use for comparison. The projects were:

1) Cont. No. 03-205404 Caltrans Dist. 03-El Dorado Co. - Rt. I-80 near Gold Run (interim report dated 1979)(27)

Table 9

ASPHALT CONTENT COMPARISON

California Test 379 (Nuclear Asphalt Content Gage)
vs
California Test 310 (Hot Extraction)

2-Teh-36 - Contract No. 189004

Date Sampled	Material RAP	Material Recycled	Test Method 379 %	Test Method 310 %
10/5/85		x	5.3	5.2
"		x	4.8	4.7
"		x	4.7	4.9
"		x	4.7	4.5
"		x	5.0	4.6
10/6/85		x	4.8	5.6
"		x	4.9	4.8
"	x		4.5	4.6
"		x	4.9	4.4
"		x	5.1	4.8
"		x	5.2	4.8
"	x		5.1	4.9
"		x	5.6	5.0
"		x	5.0	5.1
10/7/85		x	5.0	4.7
"		x	5.3	4.7
"	x		4.6	4.5
"		x	5.1	6.0
"		x	4.9	4.6
"		x	5.3	5.0
"	x		5.2	4.7
"		x	4.9	4.6
10/8/85	x		4.8	3.9
"		x	5.0	4.7
"		x	4.9	4.9
"		x	5.1	5.0
"		x	4.6	4.4
"	x		5.3	4.7
"		x	4.9	5.0

TABLE 10

PERFORMANCE RECORD (HOT RECYCLING)

Page 1 of 2
Date: 6/86
Projects Completed (*) 13

Type of Recycling: Hot-Central Plant

Dist,Co,Rte	Date Bids Open/Fin.	Tons	Contract Number	Status	Reclaimed Asphalt		Mix Formula RAP/Virgin	Recycling Agent		Performance	
					Pen.	Visc.[1]		Source	Grade	Date Review	Rating[2]
01-Men.128 Booneville 29.3/50.9	2/84 / 9/84	50,000	195374	*	15	$3x10^4$	35/65	Shell	AR 2000	5/86	Good
02-Las-395 (Litchfield) 76.5/83.4	10/80 / 1/81	33,000	128944	*	16	$3x10^4$	50/50	Douglas	AR 2000	7/85	Fair
02-Sis-97 (Weed) 0.0/10.5	6/81 / 7/82	82,000	114654	*	20	$1x10^4$	60/40	Shell	AR 1000	7/85	Good
02-Sis-5 (Weed) 22.6/25.6	6/79 / 9/79	13,200	145204	*	22	$5x10^4$	50/50	Douglas	AR 2000	7/85	Poor
02-Sis-5 (Dunsmuir) 3.1/9.2	12/81 / 11/82	33,000	150114	*	16	$10x10^6$	50/50	Shell	AR 2000	7/85	Fair
02-Sha-299 (Ingot) 45.6/50.9	10/83 / 7/84	11,670	189104	*	17	$9x10^4$	50/50	Shell	AR 2000	7/85	Excellent
02-Teh-36 (Paynes Creek) 53.3/63.8	10/84 / 10/85	28,800	189004	*	12	$4x10^4$	50/50	Shell	RA-500	5/86	Excellent

* Complete ---- X in Progress
(1) Poises @ 140°F
(2) See Table 11B for Rating Criteria

TABLE 10

PERFORMANCE RECORD (HOT RECYCLING)

Date: 6/86
Projects Completed (*) 13

Type of Recycling: Hot-Central Plant

Dist,Co,Rte	Date Bids Open/ Fin.	Tons	Contract Number	Status	Reclaimed Asphalt		Mix Formula RAP/ Virgin	Recycling Agent		Performance	
					Pen.	Visc.[1]		Source	Grade	Date Review	Rating[2]
02-Sha-44 (Viola) 28.0/43.0	4/86 / Z	52,000	223104	Advertised as an optional bid - Six bidders - all bid conventional! Not Recycled							
03-Pla-80 (Gold Run) 1.0/62.5	4/78 / 10/78	44,000	205404	*	15	$4x10^4$	50/50	Douglas	AR 2000	7/85	Poor
08-SBD-15 (Barstow) 53.8/71.7	7/80 / 9/81	58,000	218904	*	10	$6x10^4$	50/50	Witco	RA 75	4/86	Fair
08-SBD-15 (Field-Baker) 101.0/139.0	12/81 / 8/82	37,233	228004	*	10	$5x10^5$	50/50	Newhall	RA 75	3/86	Fair
08-SBD-15 (Baker Grade) 139.0/162.7	5/83 / 10/83	267,000	262004	*	25	$7x10^3$	50/50	Newhall	AR 1000	3/86	Fair
08-SBD-15 (Victorville) 40.1/43.5	11/84 / 6/85	44,000	268604	*	25	54000	50/50	Witco & Newhall	AR 1000	4/86	Excellent
11-Riv-10 (Blythe) 133.5/145.5	5/79 / 10/79	56,000	164644	*	12	$4x10^4$	50/50	Douglas	AR 1000	2/85	Failed Overlaid 6/81

* Complete ---- X in Progress Total Tons = 404,237 Total Lane Miles = 844.4

(1) Poises @ 140°F

(2) See Table 11B for Rating Criteria

TABLE 11

PERFORMANCE RECORD (COLD RECYCLING)

Page 1 of 2
Date: 6/86
Projects Completed (*) 10

Type of Recycling: Cold-In-Place

Dist,Co,Rte	Date Bids Open/ Fin.	Tons	Contract Number	Status	Reclaimed Asphalt		Mix Formula RAP/ Virgin	Recycling Agent		Performance	
					Pen.	Visc.[1]		Source	Grade	Date Review	Rating[2]
05-Mon-101 (Chualar) 77.5/82.5- 3.0/3.3	6/82 9/82	5,500	284604	*	3	$5x10^6$	100%	Witco	25	6/86	Good
05-SB-101 (Goleta) 7.1/36.0- 57.8/67.5	10/82 5/83	17,000	284804	*	4	$4x10^6$	100%	Witco	25	6/86	Fair
06-Ker-204 (Bksfld) 5.1/6.5	4/82 7/82	1,800	207304	*	7	$2x10^5$	100%	Witco	75	6/86	Fair
06-Tul-99 Kingsburg 52.7/53.4	5/82 8/82	1,600	211804	*	4	$5x10^5$	100%	Chev.	5	6/86	Fair
06-Fre-41 (Sierra - Herndon) 30.2/30.7	3/83 6/83	800	236104	*	5	$4x10^6$	100%	Witco	5	6/86	Excellent
07-LA-138 (LA) 65.5/69.3	---	---	PENDING	---	---	---	---	---	---	---	---
08-SBd-395 (Adelanto) 17.8/42.7	3/83 6/83	50,000	231304	*	22	$7x10^4$	100%	Koch	25	4/86	Fair

* Complete ---- X in Progress
(1) Poises @ 140°F
(2) See Table 11B for Rating Criteria

TABLE 11

PERFORMANCE RECORD (COLD RECYCLING)

Page 2 of 2
Date: 6/86
Projects Completed (*) 10

Type of Recycling: Cold-In-Place

Dist,Co,Rte	Date Bids Open/ Fin.	Tons	Contract Number	Status	Reclaimed Asphalt		Mix Formula RAP/ Virgin	Recycling Agent		Performance	
					Pen.	Visc.[1]		Source	Grade	Date Review	Rating[2]
08-SBd-40 (Needles #1) 50/80.4	6/26	14,600 C.Y.	003311	PENDING	---	---	---	---	---	---	---
08-SBd-40 (Needles #2) 82/140	86-87FY	----	006711--	PENDING	---	---	---	---	---	---	---
09-Mno-395 (Crowley) 9.8/17.3-1.5/4.5	4/81 8/81	6,400	086204	*	31	$5x10^3$	100%	Witco	25	12/85	Poor
09-Iny-395 Bishop 110.8/115.0	6/79 12/79	176,900	074704	*	8	$2x10^5$	100%	Witco	25	12/85	Good
09-Ker-178 (Inyo Kern) 88.4/93.0	10/81 2/82	12,000	070904	*	7	$2x10^6$	100%	Witco	5	5/82	Failed
11-Riv-10 (Chiriaco) 5.1/8.1	3/80 6/80	2,000	189914	*	?	?	100%	Witco	5	2/85	Good
11-Imp-98 (Ocorillo) 5.1/8.1	3/83 7/83	4,100	158034	*	22	$9x10^4$	100%	Koch	75	12/85	Poor

* Complete ---- X in Progress
(1) Poises @ 140°F
(2) See Table 11B for Rating Criteria

TABLE 11A

AC RECYCLING PROJECT
Status Report

Page 1 of 1
Date 6/86
Projects Completed (*) 2

Type of Recycling: Hot-Surface

Dist,Co,Rte	Date Bids Open/Fin.	Square Yards	Contract Number	Status	Reclaimed Asphalt		Mix Formula RAP/Virgin	Recycling Agent		Performance	
					Pen.	Visc.[1]		Source	Grade	Date Review	Rating[2]
02-Las-36 (Westwood)	5/76 / 9/76	135,000	130804	*	(Reclamite used, and new AC)					7/79	Poor
									Severe cracking - Skin patching by maintenance		
11-Imp-115	8/85 / 10/85	38,000	166824	*	Reclamite used -			Very poor construction - city demands an overlay. Project considered a failure due to construction techiques. State will place an overlay.			

* Complete ---- X in Progress

TABLE 11B

RATING CRITERIA FOR RECYCLED AC

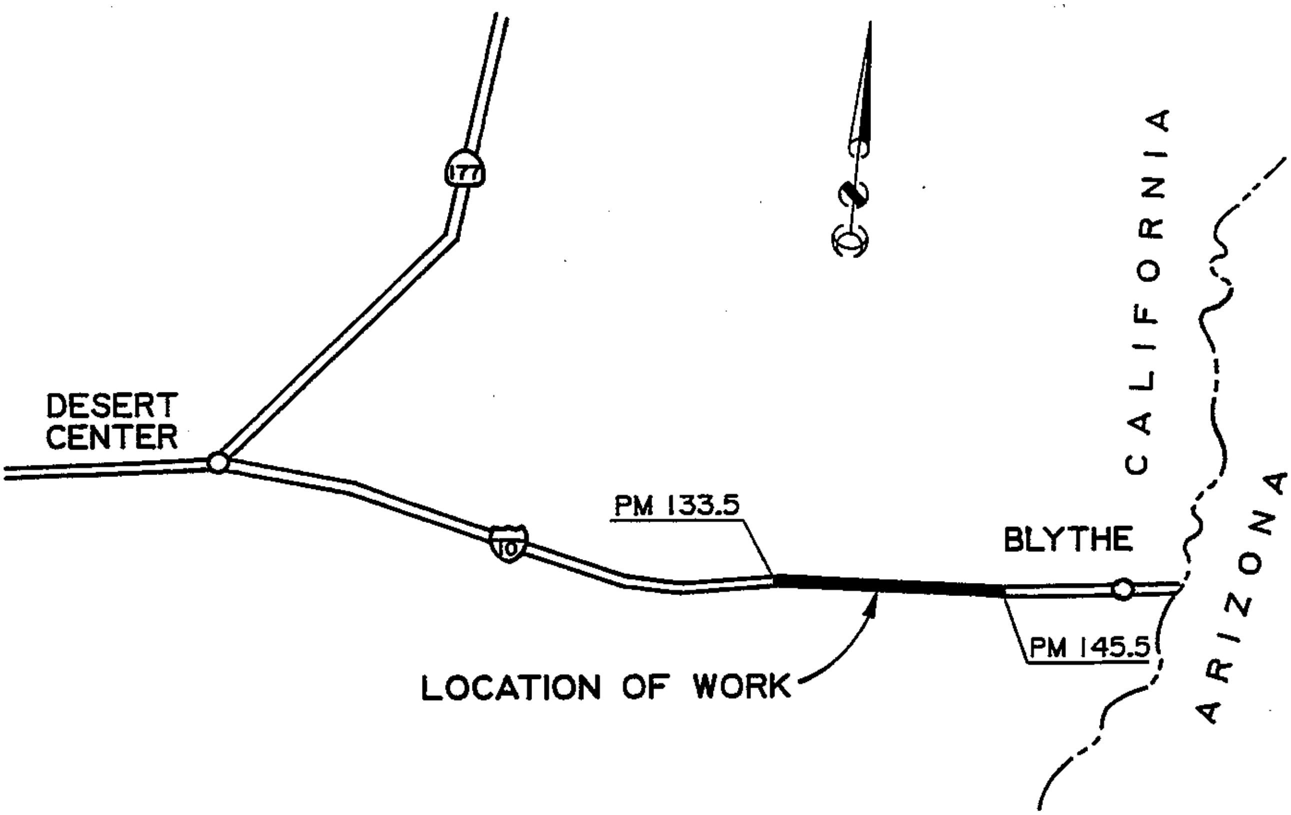
Rating	
A = Excellent	Minimal amount of cracking - nothing over 1/4" wide - no raveling, rutting, flushing, or potholing.
B = Good	Minimal amount of cracking - nothing over 1/4" wide - and/or slight raveling or rutting - no flushing or potholes.
C = Fair	Moderate amount of cracking - a few over 1/4" wide - and/or moderate raveling, rutting, flushing, with no potholes.
D = Poor	Considerable cracking and/or raveling, or rutting, or flushing, or occasional potholes, and/or considerable patching.
F = Failed	In immediate need of maintenance work due to - extensive cracking, or rutting, or flushing, or potholing, or raveling, or any combination.

2) Cont. No. 02-145204 Caltrans Dist. 02-Siskiyou Co. - Rt. I-5 near Weed(14-C)

3) Cont. No. 11-164644 Caltrans Dist. 11-Riverside Co. - Rt. I-10 near Blythe(22)

The recycled mix in each case was used directly as AC surfacing. In the case of the Gold Run project, however, the mix was confined to the shoulder area of the PCC roadway. This project was the subject of the interim report published in 1979(1).

In general, the recycling mixtures on Rt. I-80 at Gold Run and on Rt. I-5 at Weed performed as well as the control sections of conventional mix (Table 10). The mixtures placed at Blythe (Rt. I-10), however, did not perform well. This project consisted of recycling asphalt concrete pavement in 1979 on Interstate 10 near Blythe (Figure 29). It was approximately 12 miles long and consisted of recycling a large portion of the AC in the No. 2 lanes and a small portion of the AC in the No. 1 lanes of a 4-lane divided highway by the hot-central-plant process. The project consisted of three recycled mix formulas (50/50, 60/40, 70/30) and a conventional (control) mix for comparison of performance. Both AR-1000 and AR-2000 grades of asphalt were used as recycling agents. In addition, a stress absorbing membrane interlayer (SAMI) was utilized in some areas in the EB lane. No SAMI was placed in the WB lane, but one area (PM 141.20 to 141.60) did receive Petromat prior to placing the recycled mix. Work was completed in December 1979.



LOCATION MAP

NO SCALE

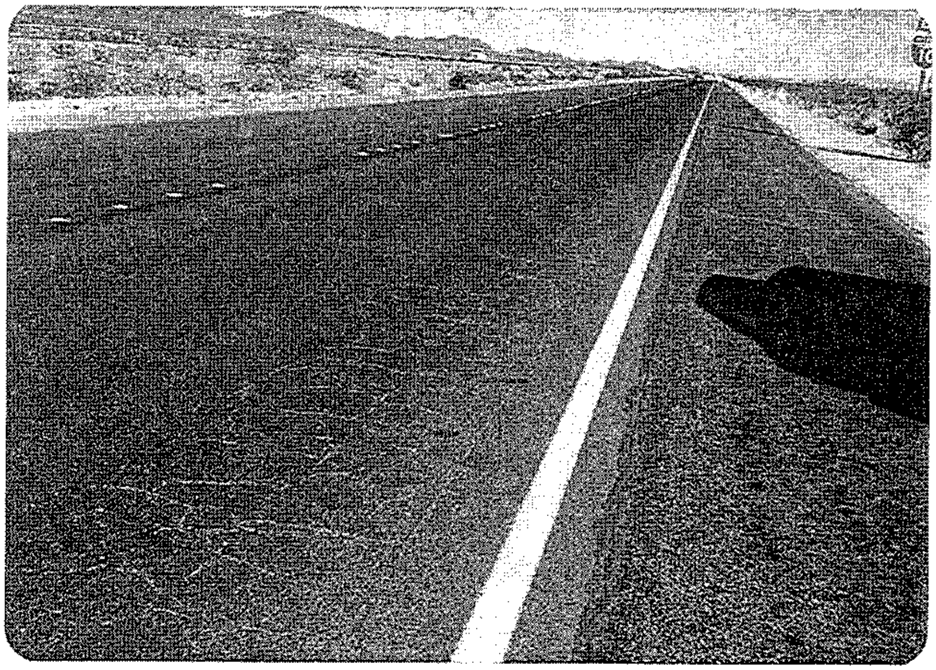
STATE HIGHWAY
IN RIVERSIDE COUNTY ABOUT 16.8 MILES WEST OF BLYTHE FROM 1.5 MILES WEST OF WILEY'S WELL RD. TO 0.4 MILES EAST OF MESA DRIVE.

BLYTHE PROJECT LOCATION

Figure 29

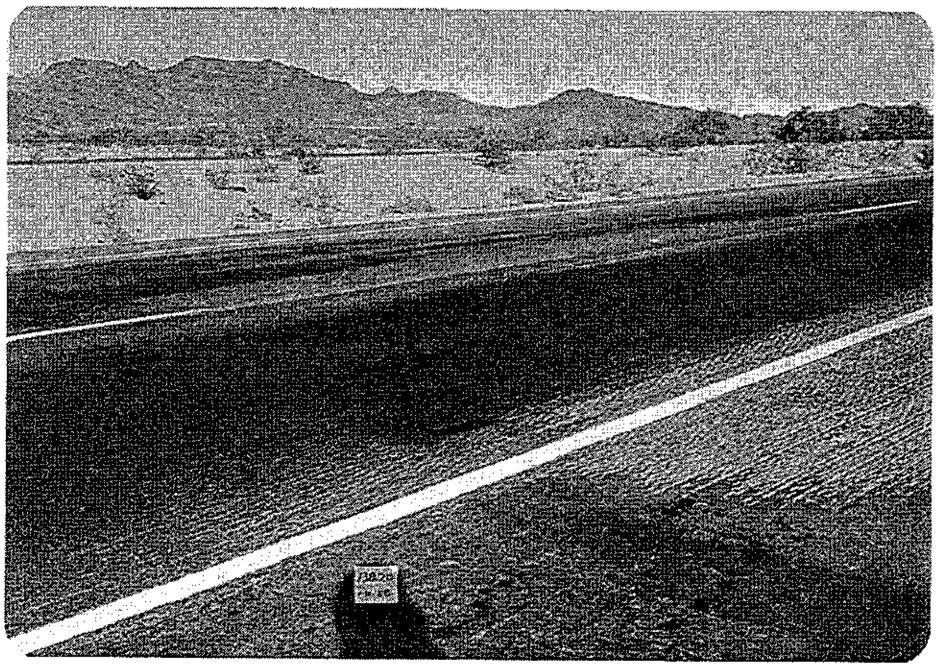
Distress, in the form of cracking, was reported within 3 months. A field review of the project, made jointly by TransLab and District 11 laboratory personnel in August 1980, confirmed the reports of cracking in the recycled mix and rutting in the conventional mix (Figures 30 and 31).

The visual appraisal of the recycled mix left the impression that the mix was dry (deficient in asphalt) and very porous as indicated by its generally coarse surface texture. To verify this, in November 1980, pavement permeability was measured at random locations in both lanes (California Test 341). Test results (Table 12) indicated that a moderate to high degree of porosity did exist in most of the recycled pavement. District personnel felt that the application of a Reclamite (an asphalt rejuvenating agent) seal coat would protect the surface from possible raveling and, hopefully, penetrate sufficiently to also soften the interior of the mix. This would provide an opportunity for additional compaction under traffic with a resultant decrease in permeability. To test their theory, several patches of Reclamite were applied with varying rates of application (Figures 32 and 33). The trial patches and adjacent areas were subsequently sampled by removing cores (Figures 34 and 35). The cores were processed in TransLab by slicing 3/8 in. thick sections from the top down. Tests on the recovered asphalt from these sections (Table 13) indicated that the consistency, as measured by the penetration test, ranged from eight in the upper slice to six in the lower slice before the application of Reclamite. With the addition of Reclamite at 0.1 to 0.3 gal per sq yd, it appeared that only the asphalt in the top 3/8 in. of pavement was affected as indicated by a somewhat higher asphalt penetration value. When the higher rate of application (0.5 gal per sq yd) was



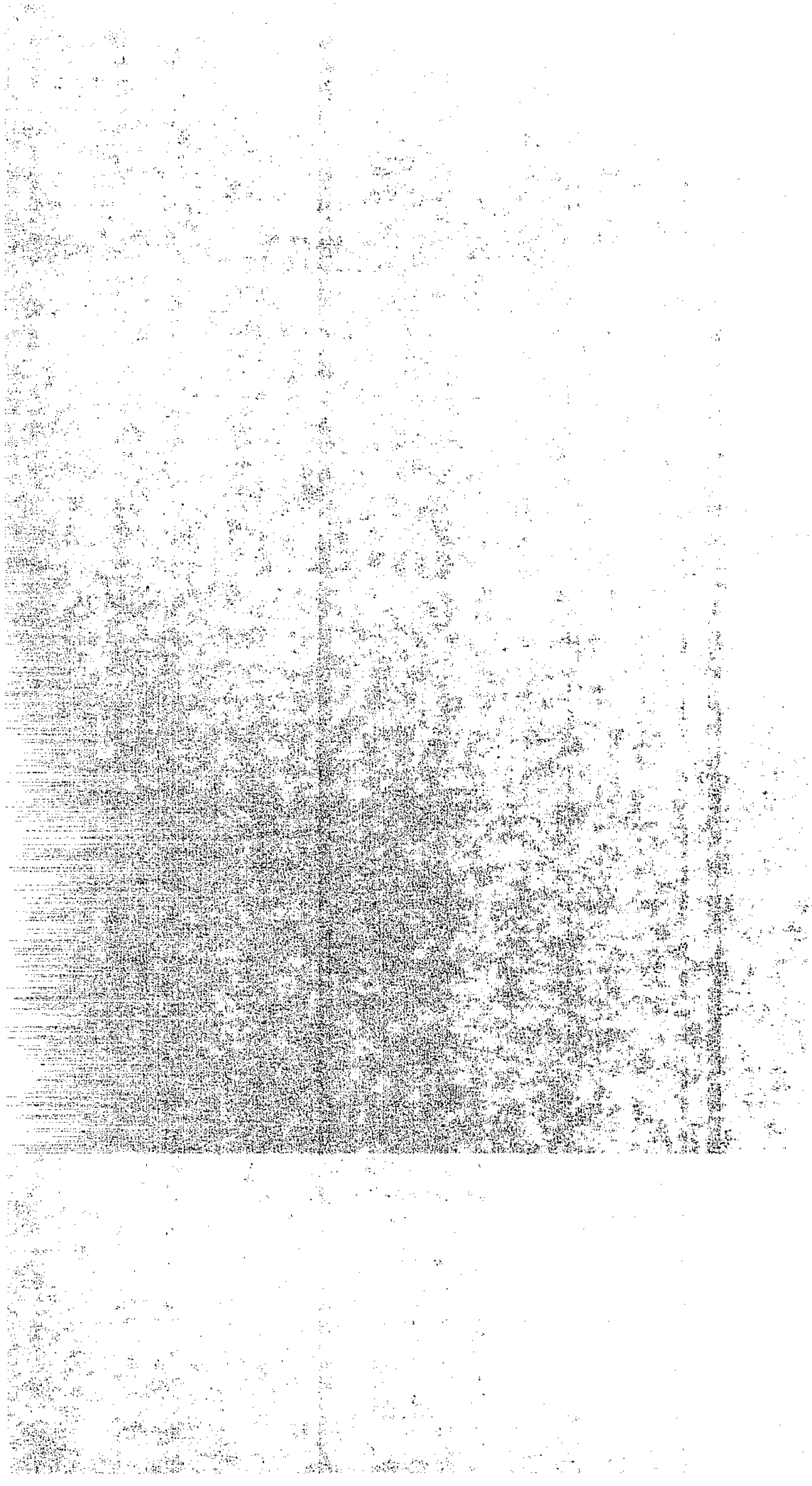
Surface Cracking On Route 10

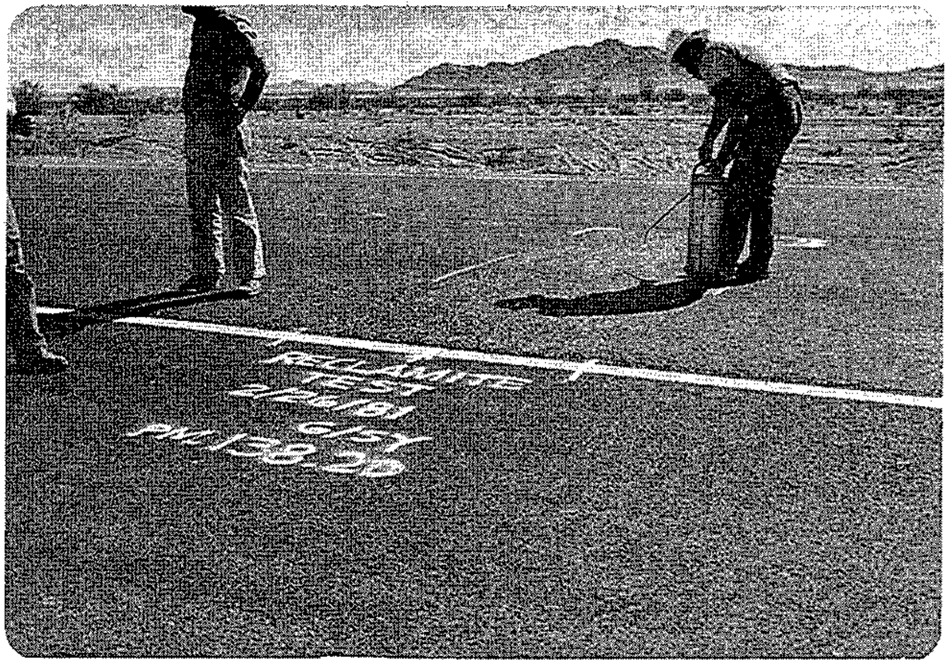
Figure 30



Surface Bleeding & Rutting On Route 10

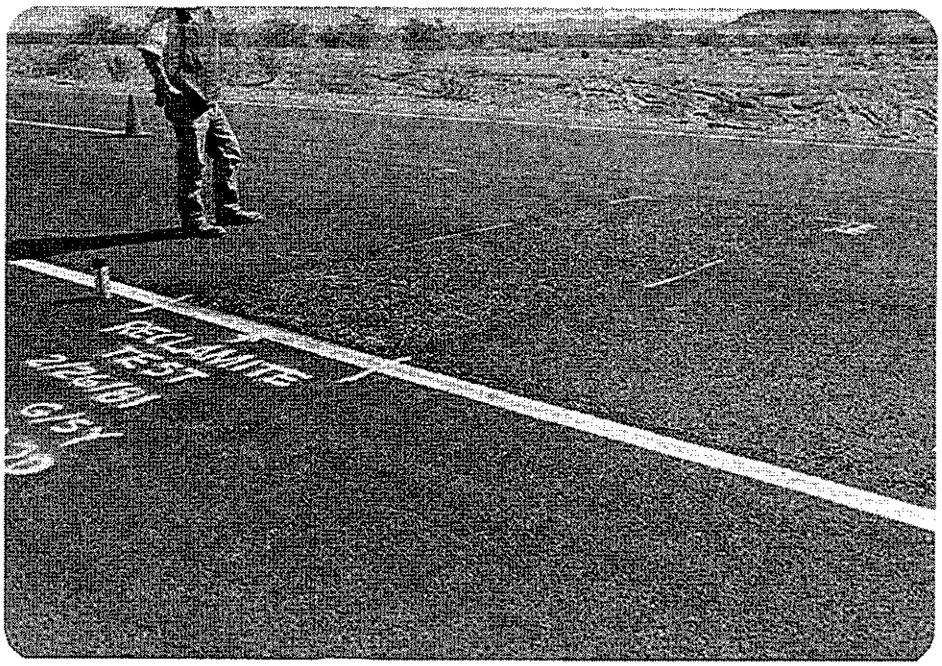
Figure 31





Applying Reclamite On Route 10

Figure 32



Finished Test Area On Route 10

Figure 33

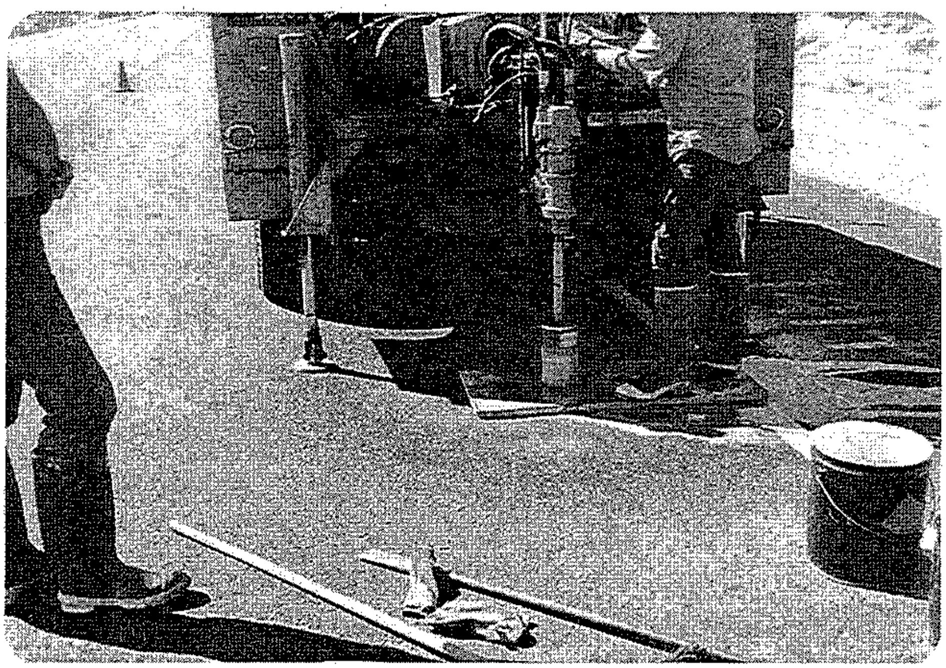
TABLE 12

RECLAMITE TEST PATCH LOCATIONS

DIRECTION	POST MILE	PERMEABILITY* Date 11-1980 (Before)	PERMEABILITY* Date 12-1980 (After)	REMARKS
WestBound	141.10	248	98	Sealed Area
WestBound	138.2	620	175	Sealed Area
WestBound	135.7	112	30	Sealed Area
EastBound	134.1	390	371	No Seal
EastBound	134.3	390	132	Sealed Area
EastBound	134.5	350	198	Sealed Area
EastBound	136.4	625+	240	No Seal
EastBound	137.4	222	240	No Seal
EastBound	141.3	220	240	Sealed Area
EastBound	143.3	300	240	Sealed Area

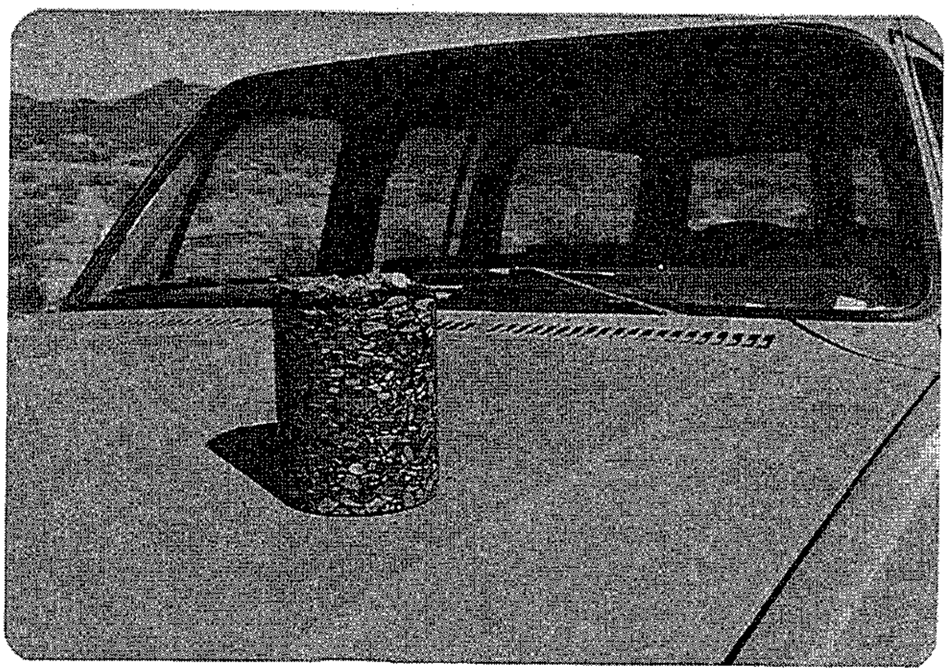
* GENERAL CLASSIFICATION OF PERMEABILITY

PERMEABILITY	CLASSIFICATION
<100	LOW
100 - 200	MODERATE
>250	HIGH



Removing Core From Pavement

Figure 34



Recovered Core to be Tested

Figure 35

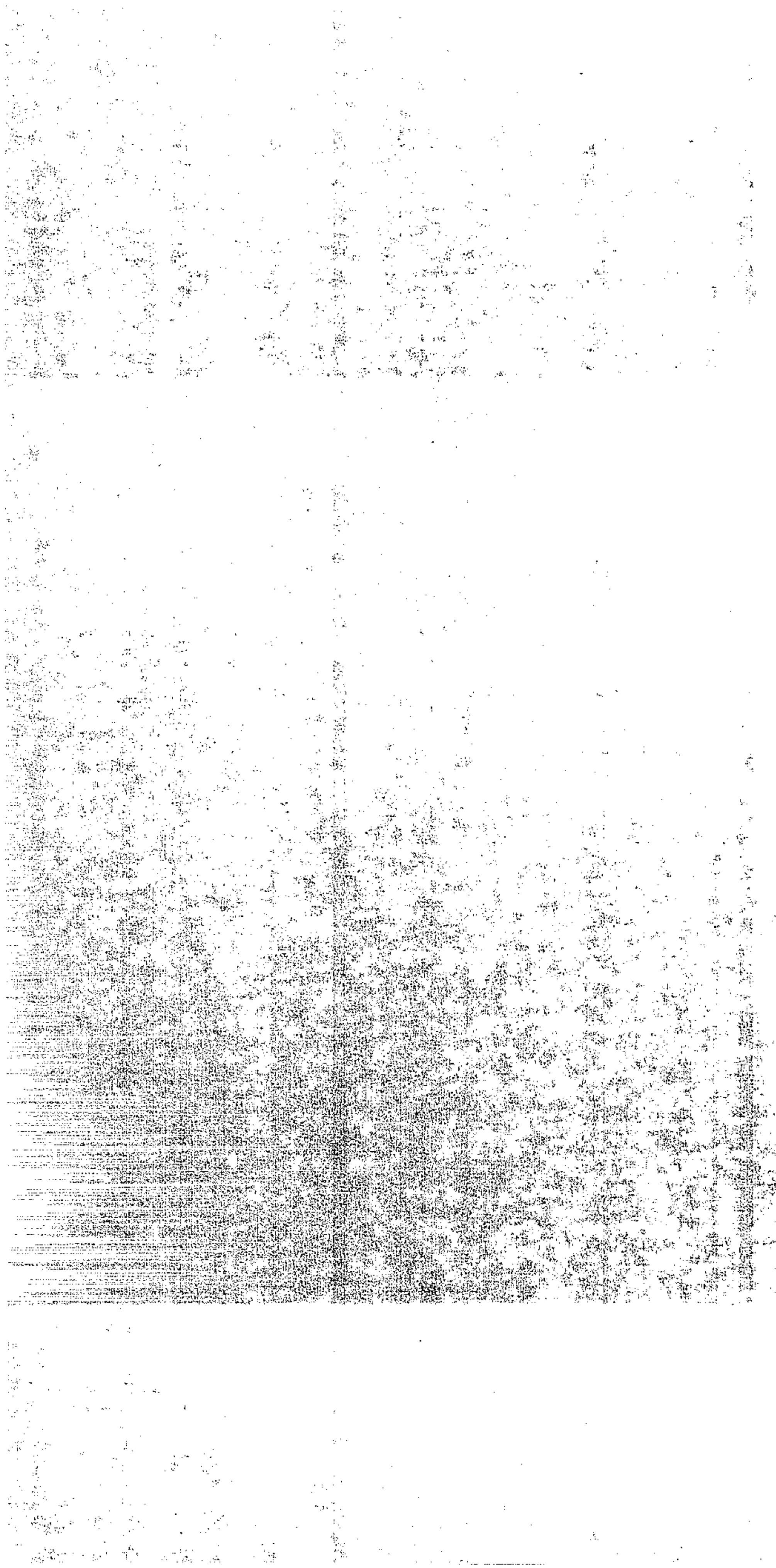


TABLE 13

RECLAMITE TEST SECTIONS

POST MILE (LANE) (TEST NO.)	RECYCLE MIX FORMULA	PAV'T PERM. (ML/MIN)	RECL. APPL. RATE (GAL/YD^2)	DATA ON RECOVERED ASPHALT: DEPTH OF TEST (INCH) (MEDIAN)		PENETRATION @77°F		MICRO. VISC. (MEGAPOISE)	
				1	2	un-treated	treated	un-treated	treated
138.2 WB (812-58)	50/50	620	0.50	1/4	3/16	8	32	184.0	9.3
				13/16	11/16	7	16	214.0	39.8
				1 5/16	1 3/16	8	11	206.0	91.0
				2	1 7/8	6	42	293.0	5.0
143.2 EB (812-59)	50/50	300	0.11	3/16	3/16	6	15	325.0	43.5
				11/16	11/16	7	8	277.0	197.0
				1 3/16	1 3/16	6	6	355.0	297.0
				1 15/16	1 15/16	3.6	6	1010.0	303.0
135.5 EB (812-60)	70/30	222	0.3	3/16	3/16	8	19	160.0	26.5
				11/16	11/16	7	4	240.0	1040.0
				1 3/16	1 3/16	8	3	205.0	1430.0
				2 1/16	1 7/8	4.5	3	610.0	1830.0
135.7 EB	70/30	112	0.15	3/16	3/16	2.8	7	1800.0	250.0
				11/16	11/16	3.1	3.5	1350.0	1100.0
				1 3/16	1 3/16	2.5	3.9	2150.0	870.0
				1 15/16	2 1/8	3.2	2.9	1280.0	1650.0

(1) Untreated Section

(2) Treated Section

used, all the mix was softened to some extent. The top 3/8 in. and the bottom 3/8 in. appeared to be softened the most. The lowest section actually had the softest asphalt. This reflects drainage from the surface (permeability in the area was 600+) due to the high rate of application. Although somewhat disappointed by the depth of softening revealed by the test patches, the District still felt that softening and the possibility of subsequent tightening of the upper 3/8 in. of the pavement would be possible and beneficial. Therefore, a fog seal of Reclamite was applied with rates ranging from 0.1 to 0.3 gal per sq yd. The actual rate depended on the field permeability that was determined earlier for the various sections. The seal was applied in July 1981; however, no seal was applied to the areas considered rich (conventional mix area). The rich areas were subjected to surface grinding using a cold planer to remove the ruts and free asphalt.

In general, the District's decision to seal was a good one. Although cracking was not eliminated or halted, surface raveling was arrested, and the permeabilities were reduced by as much as 50% (Table 12), thus extending the life expectancy of the pavement.

In March 1981, prior to sealing, cores of the pavement were taken in both lanes and forwarded to Sacramento for analysis. The cores, in general, were rather dry looking and exhibited a considerable amount of voids. Because of the need to test the cores for various physical properties such as asphalt content, M_R, and viscosity and penetration of the recovered asphalt, no "as received" specific gravity was determined due to the contamination that would have occurred when coating the cores with wax.

The test data from the cores (Table 14) indicated that the recovered asphalt was low in penetration and high in viscosity. The measured asphalt consistency after recycling was, in fact, essentially equal to that of the recovered asphalt prior to recycling. The ductility of the binder recovered from this relatively new pavement was also very low. The test data (Table 15) also revealed that the viscosity of the new asphalt being used as a recycling agent was within specifications at the time it was used. However, the quantity added was very low as indicated by extraction tests (Table 14). Thus, the addition of the new asphalt (both AR-1000 and AR-2000) with normal viscosity (Table 15) for their respective gradings, apparently resulted in little or no softening of the aged asphalt.

Although various mix formulas were apparently used, the extracted gradation was essentially the same within each lane but the WB lane had the finer mix with regard to the amount passing the No. 4 sieve. Thus, it appears that gradation contributed to the cracking because the greater amount of cracking appeared in the coarser EB lane.

In December 1981, five months after the recycled sections were sealed, field permeabilities were again measured (Table 12), and a noticeable decrease was evident in the sealed areas. A field review at this time revealed no surface raveling, but cracking was continuing to develop in the recycled mix and surface flushing and rutting were again developing in the conventional (control) mix. At this time, it was estimated that 60% of the pavement in the #2 EB lane and 18% of the #2 WB lane were in poor condition. Also, the roadway performance in the areas with the SAMI (PM 133.89 to 137.95) was classified as poor to fair (Table 14). However, the areas in the WB lane with the Petromat were classified as good.

TABLE 14

TEST DATA
11-RIV-10

SAMPLE NO. 812-	POST MILE	MIX	ASPHALT GRADE	DEPTH OF RECY	CORE DATA (RECOMPACTED IN LAB)				RECOVERED ASPHALT DATA					GRADING (% PASSING)				DEFLECT. (80th %)		PREFORMANCE RATING (12-81 SURVEY)
					SP GR	M_R (X10^5)	STAB	COHES	PEN	VISCOSITY 140°F	VISCOSITY 275°F	DUCT	% ASPH.	1/2"	#4	#30	#200	PRE CONST 8-79	2 YR POST CONST 10-81	
15	134.50 EB	50/50	AR-1000	0.3'	2.32	5.66	37	355	9	1,650,364	5,605	4.50	4.2	87	47	21	10	.022	.022	Fair (Small Cracks)
16	135.20 EB	60/40	AR-1000	0.3'	2.34	5.73	45	470	8	6,456,410	7,290	1.75	3.6	91	49	22	10	-	.021	Poor (Crack)
17	135.60 EB	70/30	AR-1000	0.3'	2.33	5.02	45	455	6	19,385,510	18,687	0.50	4.1	87	49	23	9	-	.029	Poor (Crack)
18	136.20 EB	70/30	AR-1000	0.3'	2.31	5.35	53	710	5	35,428,266	20,436	0.50	3.8	89	52	23	10	.018	.021	Poor (Crack)
19	136.85 EB	60/40	AR-1000	0.3'	2.36	5.49	45	490	12	554,050	3,462	4.50	4.0	83	48	21	10	-	.024	Poor (Crack)
20	137.50 EB	60/40	AR-1000	0.3'	2.34	5.52	47	720	7	9,830,494	13,254	0.75	3.8	83	47	21	10	.013	.021	Fair (Small Cracks)
21	138.20 EB	Type B	AR-2000	0.2'	2.39	5.39	25	420	-	-	-	-	-	-	-	-	-	-	-	Poor (FL)
22	140.75 EB	Type B	AR-2000	0.6'	2.41	4.72	32	330	19	33,045	1,021	93	4.8	86	51	25	8	.017	.012	Poor (FL & Cracks)
23	144.85 EB	50/50	AR-1000	0.6'	2.37	4.99	38	440	9	541,410	3,141	4	5.3	88	51	21	10	-	.015	Good
24	145.50 EB	Type B	AR-2000	0.2'	2.42	4.22	38	390	20	33,586	989	65	4.2	89	51	25	9	.009	.006	Good
25	144.75 WB	50/50	AR-1000	0.5'	2.31	4.98	51	1035	4	44,893,728	33,407	0	3.9	89	57	24	11	-	.018	Good
26	144.65 WB	60/40	AR-2000	0.4'	2.37	4.94	29	360	11	693,737	3,874	4	4.8	95	56	20	12	-	.022	Good
27	144.20 WB	60/40	AR-2000	0.4'	2.31	4.85	45	750	6	10,605,821	11,481	0	4.5	93	60	33	12	-	.026	Good
28	144.00 WB	60/40	AR-2000	0.4'	2.31	-	48	840	4	12,496,224	15,626	0	3.5	83	52	24	11	-	.022	Good
29(Top)	143.56 WB	50/50	AR-2000	0.2'	2.33	5.02	48	790	6	19,931,919	19,043	0	4.4	90	58	25	11	-	.023	Fair (Small Cracks)
29(Bottom)	143.56 WB	60/40	AR-2000	0.2'	-	-	-	-	-	-	-	-	4.6	88	52	24	11	-	.023	Fair (Small Cracks)
30(Top)	143.51 WB	50/50	AR-2000	0.2'	2.32	5.60	52	880	5	4,763,972	7,266	0	3.6	86	54	23	11	-	.023	Fair (Small Cracks)
30(Bottom)	143.51 WB	60/40	AR-2000	0.2'	-	-	-	-	8	1,195,930	4,383	2.50	4.0	88	60	25	10	-	.023	Fair (Small Cracks)
31(Top)	143.15 WB	50/50	AR-2000	0.2'	2.32	4.89	39	630	5	3,688,411	6,630	0.50	4.4	90	58	20	11	-	.023	Poor (Cracks)
31(Bottom)	143.15 WB	60/40	AR-2000	0.2'	-	-	-	-	7	4,216,522	7,014	1	4.6	88	52	19	11	-	.023	Poor (Cracks)
32	142.00 WB	50/50	AR-1000	0.4'	2.33	5.39	42	600	9	834,132	3,276	3.75	3.8	86	60	22	10	-	.024	Good
33	141.50 WB	50/50	AR-1000	0.4'	2.36	4.84	32	570	9	1,516,332	5,592	4	4.1	94	56	25	11	-	.024	Good

TABLE 15

SUMMARY OF TEST RESULTS - PAVING ASPHALT
(11-Riv-10)
(Average)

ASPHALT GRADE	TEST ON RESIDUE FROM RTF - AASHO - T240						TEST ON ORIG. ASPH.	
	ABSOLUTE VISCOSITY 140°F(Poise)	KINEMATIC VISCOSITY 275°F(CS)	PENETRATION AT 77°F	% ORIGINAL PENETRATION	ORIG. PEN.	DUCTILITY AT 77°F(CM)	FLASH POINT PMCT(°F)	SOLUBILITY IN TRI-CHLOR (%)
AR-1000	1289	189*	94*	62*	153*	100+*	400+*	99.9*
AR-2000	1992	279*	62*	61*	102*	100+*	425+*	99.9*
AR-4000	4210	347	48	61	65	75+	474	99.9

*ONE VALUE ONLY

Pavement deflection measurements (Table 14) indicated that recycling did not result in an appreciable decrease in deflections (perhaps due to the cracked condition of the "new" pavement). The amount of deflection, however, is considered relatively low, both before and after recycling. Therefore, the cracking appears to be associated more with the amount and hardness of the asphalt than with deflection although even slight deflections can cause fatigue.

Summary of the Blythe Project

Although some areas of this project are performing well in spite of indications of hard asphalt binder, it is felt that cracking is imminent. It appears that the premature cracking on the greater portion of this project was the result of:

1. Excessive hardness of the asphalt binder in the mix due to the ineffectiveness of the recycling agents used and/or failure to baffle the flame in the drier sufficiently to protect the salvaged AC and new binder, and,

2. Insufficient binder, and

3. High pavement permeability due to coarse aggregate gradation and/or inadequate compaction.

The flushing and/or bleeding of the conventional mix was due simply to excess asphalt caused by an inappropriate degree of reliance upon previous experience, regarding asphalt demand, with similar materials in this area.

In the immediate future, a program of light applications with Reclamite every other year (if the permeability permits) may extend the life of the pavement until such time that funds are available to resurface the roadway. It was evident that traffic alone was insufficient to lower the permeability to any great degree (see Table 12).

To avoid such a situation in the future, it is suggested that:

1. More attention to preliminary mix design in the laboratory be exercised:

2. Recycling agents be employed:

3. Attempt no more than two recycled mix formula variations per project (in addition to a conventional mix section for control);

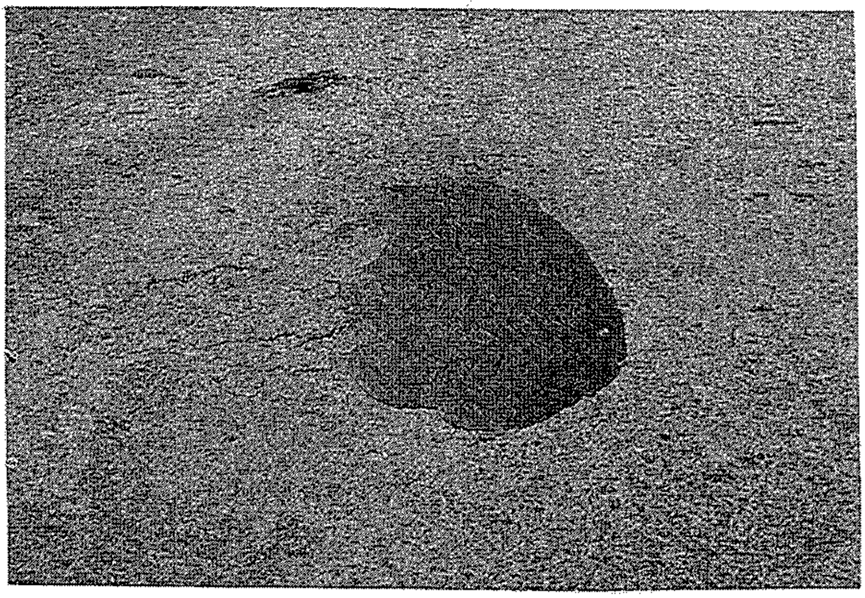
4. Better shielding of the salvaged AC and new binder from the flame in the drier-drum be considered as the veil of virgin aggregate used on this project was not effective.

2. <u>Cold Recycled Mixes</u>

In California cold recycled mixtures have been in service for periods up to 8 years. The fact that cold recycled mixtures are generally overlaid with at least 1 1/2 in. of conventional hot mix makes the overall performance evaluation a more lengthy project. However, one cold recycled project did fail early (within 3 months after placing) due to instability. This project, Rte. 178 near Inyokern(14), called for cold-in-place recycling using a light emulsified recycling agent (ERA-5). A depth of 0.30 ft was recycled and then overlaid with 0.10 ft of conventional hot mix. Due to a rain storm prior to overlay, 3 to 4% moisture was trapped in the recycled mix at the time of overlay (10 days after the rain). The result was the appearance of rich spots on the surface caused by an upward migration of recycling agent into the conventional overlay due to moisture vapor action (Figure 36). District laboratory tests reported as high as 0.7% more asphalt in the overlay (as a result of the moisture vapor action) than was originally used. Rutting followed the appearance of the rich spots.

This project is located in the hot desert area of southern California. Air temperatures reached over 100°F during the period immediately following placement of the overlay. The consequence was a complete failure due to surface rutting and pushing under traffic (Figures 37 and 38). Some sections rutted so severely that complete excavation and replacement was required in six months.

The cold recycled mix placed on two projects completed prior to the Inyokern project (and two after) in an almost identical environment had less than 1.0% moisture at time of overlay. Both are performing well. Also, a project placed on the coast on State Route 1 (located in a damp area with maximum temperature of 70°F) is performing well. In this case, the cold recycled pavement was overlaid 24 hours after recycling while containing an estimated 2.0 to 2.5% moisture. Thus, it appears that a combination of high moisture content and high temperature is the most dangerous situation. As a result of the Inyokern failure, in areas where ambient temperatures reach 100°F several times a year, specifications were formulated stating that the

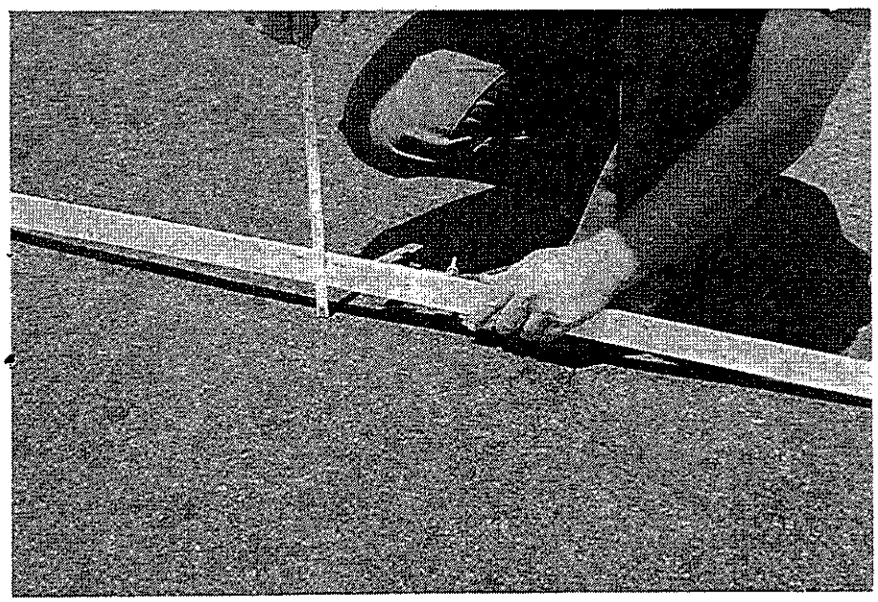


Rte. 178 - Inyokern
Fat Spots or "surface boils" due to moisture vapor action.

Figure 36

Rte. 178 - Inyokern
Rutting

Figure 37



Rte. 178 - Inyokern
Rutting

Figure 38

moisture content of the cold-in-place recycled pavement could not exceed 1.5% at time of overlay. A 2.0% maximum was adopted for cooler areas.

Field experience with fog seals on cold recycled mixes to prevent raveling revealed that an application within 24 hours had a tendency to trap moisture in the mix and thus retard curing. In some cases, due to a lack of penetration of the seal, tire pickup and tearing of the surface occurred (Figure 39). In most cases where a seal was not applied, a slight amount of raveling was also evident; however, within 24 hours the condition stabilized. Traffic has used cold-recycled surfaces for as long as six weeks before placement of the hot mix cap. However, due to the possibility of a slippage failure caused by loose material (sand particles) on the surface, it is recommended that a light tack coat (.05 gal per sq yd) be applied just prior to overlay.

3. Hot Surface Recycling

Hot surface recycling consists of heating in-place and recycling the top 1 in of the pavement. The operation usually consists of two or three heater scarifiers working in tandem. The last unit scarifies the heated surface for a depth of up to 1 in. The scarified material is then treated with a rejuvenating agent and recompacted.

California has utilized this method on two state highways. Due to extensive and severe thermal cracking of the pavement prior to recycling, the surface-recycled pavement on a 1976 project in northern California did not perform well(28). Reflection cracking and spalling occurred (within 6 months). A second project (Rt. 115 through the

Surface Raveling as a Result of a
Surface Seal.

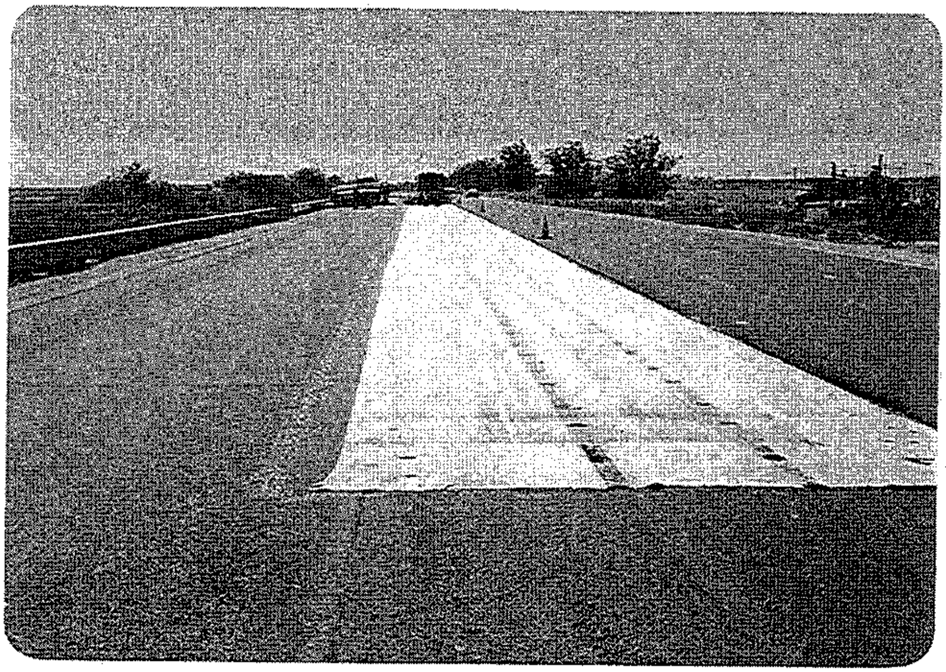
Figure 39

city of Holtville) was so badly constructed that plans were formulated for an immediate overlay. The scarifier tines did not penetrate deeply enough due to rutting and/or insufficient heating. The result was areas that were not recycled("holidays") and, with only a thin layer of recycled mix screeded over these areas, they rapidly raveled under traffic. Thus, until deeper heating and recycling techniques are developed, this method of recycling has not been found adaptable to state highway projects where cracking is the primary distress. It is, however, being considered for areas where slight surface bleeding and/or rutting has started. It is also being used occasionally on city and county projects in California.

In the city of Anaheim, in May 1985, a contractor successfully demonstrated a new machine built in Japan that will mill 1 in. of heated surface, recycle the material, and simultaneously place a new hot-mix cap. It operated at about 25 ft per min. while milling and mixing 0.1 ft of RAP and simultaneously placing a hot cap 0.1 ft thick. The end result appeared to be an excellent pavement comparable to 0.2 ft of conventional AC. Additional projects are planned utilizing this approach.

H. Recycling AC Mixes That Contain Paving Fabric

The use of paving fabric in asphalt concrete overlays as a deterent to reflection cracking has recently gained widespread acceptance (Figure 40). However, fabric use has raised questions as to the ability to recycle such pavements. Items such as milling, mixing, and/or air pollution from burning fabric have need of answers. Thus, in 1980, an addendum to this recycling research project was approved that provided additional funds to study the effect of various fabrics on pavement recycling operations.



Pavement Reinforcing Fabric

Figure 40

The pavement selected was in northern California on I-505 near the city of Winters, California. A section of the southbound inside lane containing four different fabrics placed as part of a previous experimental project in 1980 was selected for study. With the use of a cold planer (CMI Roto-Mill PR225 Figure 41), cuts 55 in. wide were made to and through the fabric. In addition, the cutting teeth used and speed of travel were also varied. Two types of teeth were used (Figure 8); 1) the standard conical (C-3) normally used for AC, and 2) the wedge or chisel tooth. The purpose of this work was to determine:

1) The effect of various fabrics on milling and recycling.
2) The effect of a given tooth when milling pavement containing fabric.
3) The effect of depth of cut when milling pavement containing fabric.
4) The effect of speed of travel when milling pavement containing fabric.

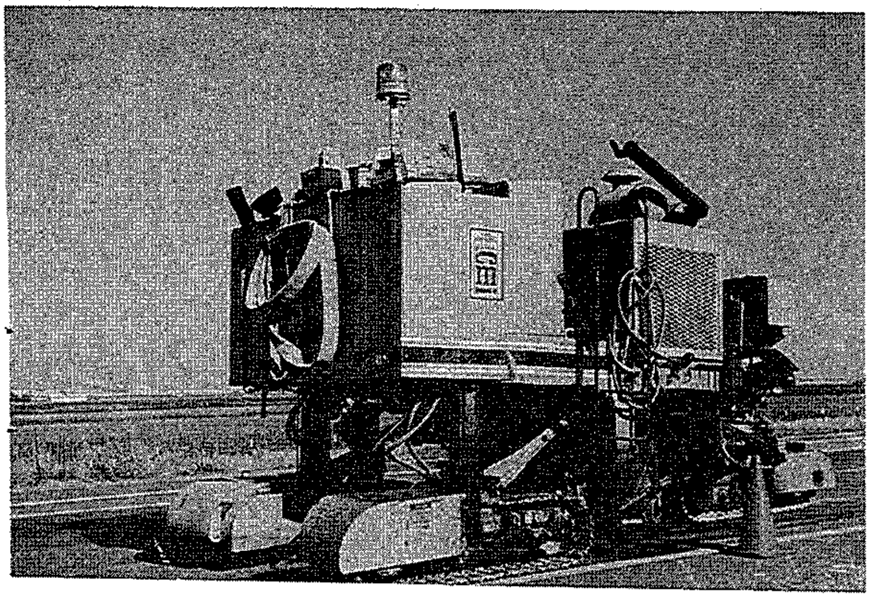
After milling, the fabric was in strips about 1 in. x 3 in. (Figure 42); however, some also "caked" around the teeth on the mandrel (Figure 43).

The conclusions regarding recycling RAP containing fabric were:

1. Fabric does not significantly effect milling.

2. The type of tooth had no significant effect on milling except at slow speed.

3. The depth of cut below the fabric had no significant effect on milling.

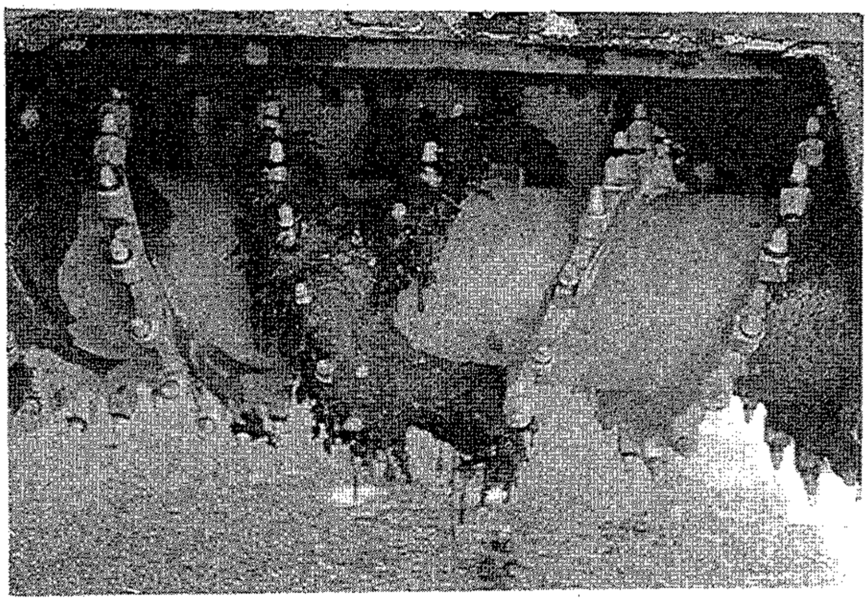


CMI Model 225
Roto Mill

Figure 41

Strips of Fabric
After Milling

Figure 42



Fabric "Caking" on
Mandrel

Figure 43

4. Milling speed had a slight effect on the size of the fabric pieces created by the milling operation. The larger pieces resulted from milling at slow speed with the chisel tooth.

A detailed report of this study is presented in Appendix B.

I. Energy Saving Estimate

The only comprehensive study of energy savings due to recycling was reported in the 1979 interim report(14) by Doty-Scrimsher. It was reported that hot recycling (at that time) resulted in a 15% savings of energy.

J. Cost Analysis

When comparing the cost of recycling vs nonrecycling alternatives or possibly hot central plant vs cold recycling, the general conclusion was that initially cold recycling could provide as much as a 20-40% cost saving and hot recycling a 15-25% saving. However, this conclusion assumes that structural adequacy is realized with cold recycling. Due to insufficient data and experience, a cost analysis of hot surface recycling was not made. Each project, of course, must be analyzed from a local construction cost standpoint. However, regardless of the cost savings, the savings in raw materials such as aggregate, asphalt or fuel oil, is substantial in any method of recycling. The cost based on life span or performance is yet to be evaluated.

K. Summary

Although most of the recycled mixtures are showing various degrees of cracking - the same condition and performance is being recorded with conventional mixes of the same age. Therefore, the performance of recycled mixes, for the most part, has been as good as that of conventional mixtures (Figure 44). As of January 1986, California had recycled 21 large projects (approximately 1,000,000 tons). Eleven projects were recycled by the hot central plant process and 10 by the cold-in-place process. One large project attempted to use the hot surface recycling process but was less than successful(28). In addition, one cold recycled project (14-H) and one hot recycled project(22) were less than successful. Each of these projects were investigated and the reasons for failure was discovered and corrected by specification and/or procedural changes.

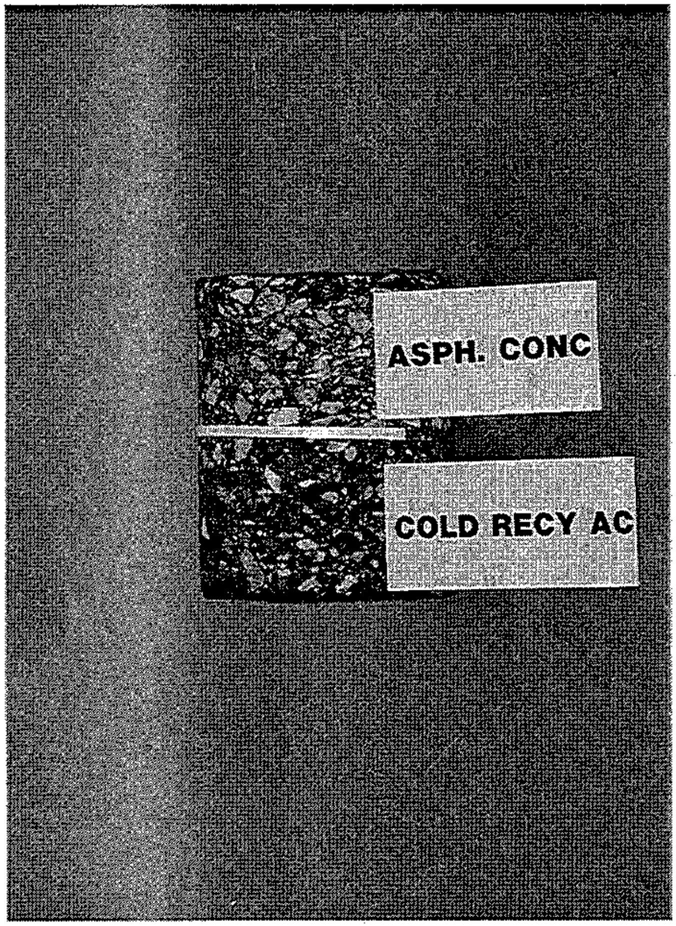
In 1985, cores were obtained (Figure 45) from several completed projects and asphalt hardness was determined (Table 7). Test data relative to asphalt hardness is somewhat misleading considering that the system of recovery of the asphalt (Abson Recovery) causes a complete blending of aged asphalt and recycling agent that may or may not occur to the same degree in hot mixes and definitely will not occur immediately in cold mixes placed in the field. Therefore, considerable credence was given to visual observations of the core and pavement condition, particularly on the cold-recycled projects. Visual inspection of the cores indicated the recycled mix from both hot and the cold jobs was difficult to distinguish from conventional AC obtained from the same projects.

L. Need for Additional Research

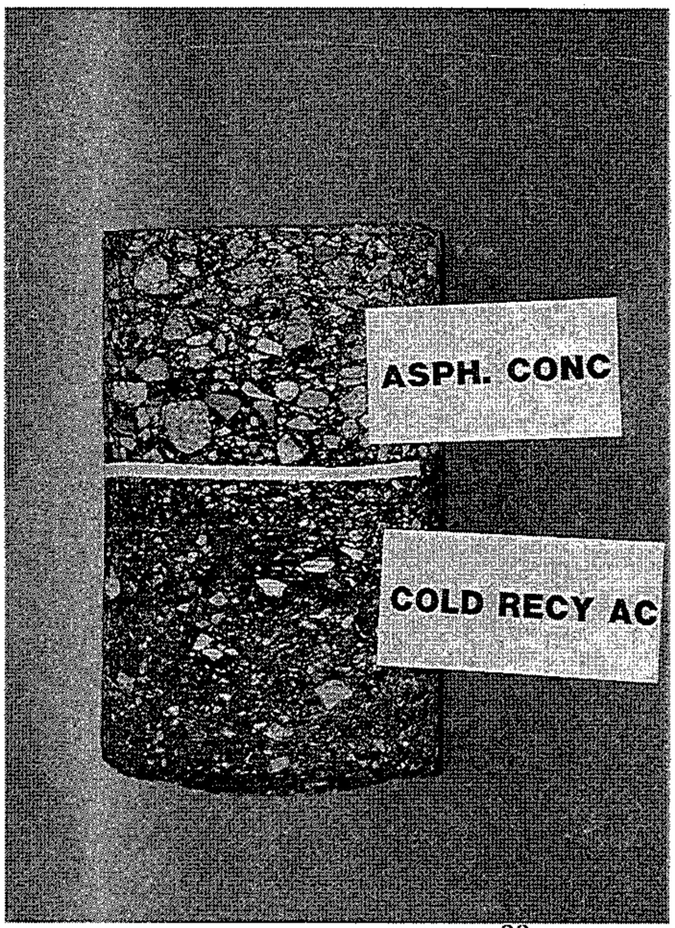
The following items are in need of additional study to better utilize recycling of asphalt concrete pavements:

Figure 45

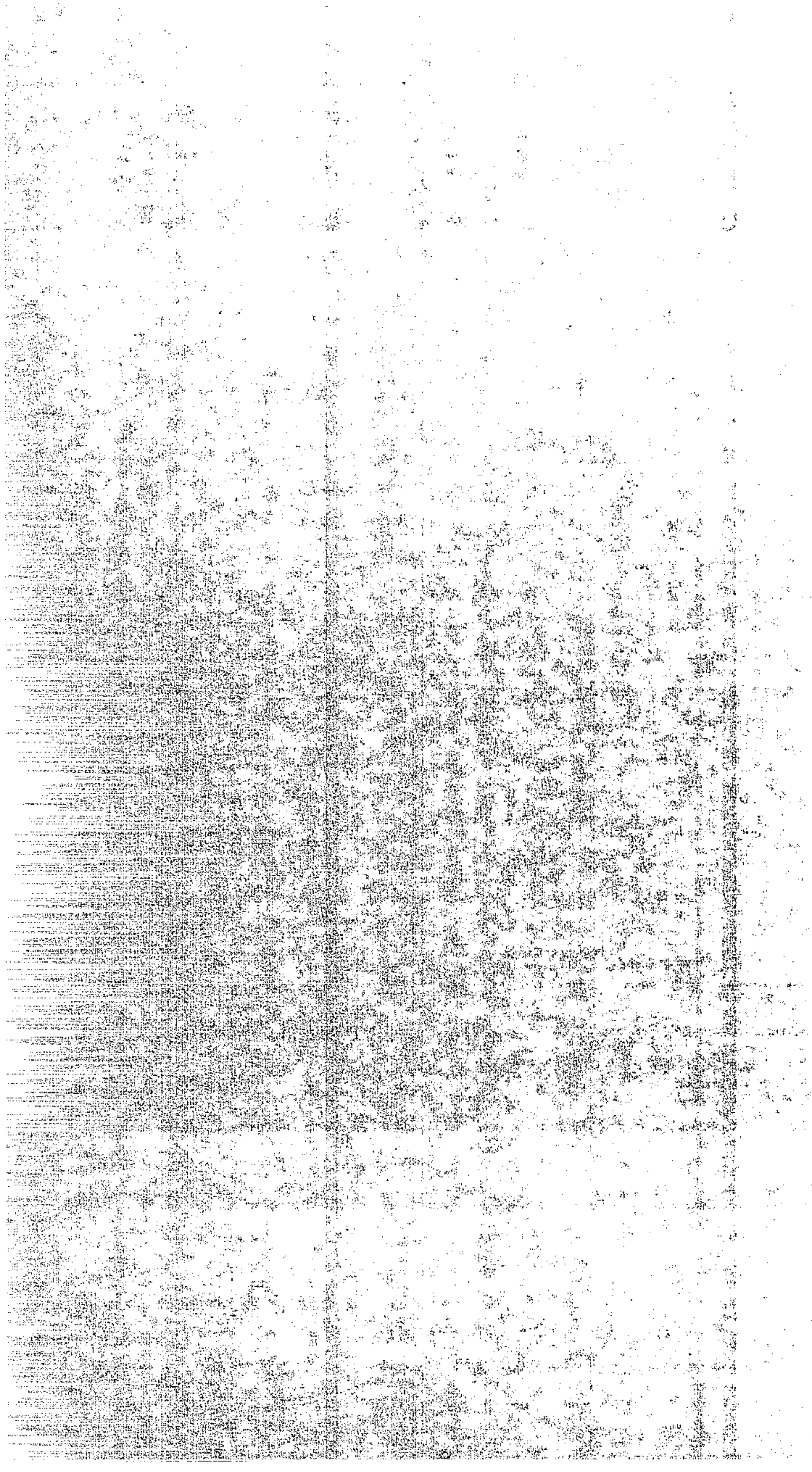
Pavement Cores From Cold Recycled Projects



a) Adelanto



b) Bishop



1) Recycling Agents

a) Lab tests to define softening capabilities, other than viscosity tests of recovered asphalt. The method of obtaining a sample (Abson Recovery) of asphalt for measurement of consistency creates an artificial blend that is not necessarily representative of the actual field conditions (especially with emulsified recycling agents).

b) Standard specification on physical makeup of emulsified recycling agents. There is presently no way to test the residue of such agents. The alternative now used is to test two materials,

1) the emulsion and,
2) a sample of the alleged base-stock used.

2) Cold Recycling

a) Methods of field compaction.
b) Methods of rapidly determining binder and moisture content during construction.
c) Method to determine rate and extent to which the aged asphalt is rejuvenated.

3) Hot Recycling

a) Method of controlling air pollution at the drier-drum.
b) Method of rapidly determining binder and moisture content during construction.

4) Hot Surface Recycling

a) Methods of obtaining deeper penetration of heat (at least 2 in.).
b) Method of analysis of roadway conditions to make this method of recycling potentially more successful.

5) Laboratory Design

a) A fast method, other than, or in addition to viscosity, to designate the appropriate recycling agent to use to avoid artificial blending.

b) Better test procedures for possible water-related problems.

c) Better tests to evaluate cold recycled mixtures in terms of stability and durability.

6) Performance

Long-term (10 years) evaluation of recycled mix performance in comparison to conventional mixes in the same environment for the same period.

REFERENCES

1. LeClerc, R. V., Walter, J. P. "Design and Performance of Asphalt Bases in the State of Washington," Washington State Department of Highways - Transportation Research Circular N177 - June 1976.

2. Ingberg, R., Telephone discussion on December 13, 1977, Minnesota Department of Transportation.

3. Ingberg, R., "Evaluation of Recycling Bituminous Pavement," Minnesota Department of Transportation, St. Paul, Minnesota - November 1976.

4. Davidson, D. D., Canessa, W., Escobar, S. J., "Recycling of Substandard or Deteriorated Asphalt Pavements - a Guideline For Design Procedures," Witco Chemical, Golden Bear Division, Bakersfield, California - February 1977.

5. Smith, C. L., "Recycling Asphalt Pavements - Republic County, Kansas," Republic County Materials Engineer, U.S. Department of Transportation.

6. Mandy, J., Wolfgram, V. H., "Milling Bituminous Surfacing in North Dakota," Highway Focus - Volume 10, U.S. Department of Transportation, Federal Highway Administration - February 1978.

7. Henry, J. W., "Surface Recycling in Alaska," Alaska Department of Transportation and Public Facilities, Highway Focus - Volume 10, U.S. Department of Tranpsortation, Federal Highway ADministration, February 1978.

8. Epps, J., Transportation Research Board, Texas A&M, "Energy Requirements Associated with Highway Maintenance and Rehabilitation," 1978.

9. McEven, Skinner & Technician Inc., Berkeley, California, "A Technical and Economic Study of Waste Oil Recovery," 1975.

10. The Asphalt Institute, "Energy Requirements for Roadway Pavements," Misc. 75-3, April 1975.

11. Gorden and Associates, "Energy Efficiency Improvement Targets," Petroleum and Coal Products, Vol. 1, New York, June 25, 1978.

12. Apostolos, John, "Energy 3 Program Description," prepared for Caltrans Transportation Laboratory, June 1978.

13. Apostolos, Shoemaker, Shirley, "Energy in Transportation Systems," Caltrans Transportation Laboratory, November 1978.

14. Scrimsher, T., Project report memos to file, Caltrans Transportation Laboratory, Sacramento, California:

A.	Crawley - Rt. 385	1981
B.	Bishop - Rt. 395	1979
C.	Weed	1979
D.	Blythe	1979
E.	El Dorado Co.	1980
F.	Kern Co.	1980
G.	King Co.	1981
H.	Inyokern	1982
I.	Barstow	1981
J.	Bakersfield Rt. 204	1982

K.	Litchfield	Rt. 395	1981
L.	Adelanto	Rt. 395	1982
M.	Kingsburg	Rt. 99	1982
N.	Fresno Co.	Rt. 41	1981
O	Ocotillo	Rt. 98	1983

15. FHWA & Caltrans Proceedings, Asphalt Concrete Recycling Seminar, September 1981.

16. Ingberg, R. C., Progress Report on Maplewood, Minnesota Recycling Project, Minnesota Department of Transportation, Investigation No. 646, St. Paul, Minnesota, 1976.

17. Lindley, B. R., Billingsly, Jr., N. A., "Recycling of Asphalt Concrete Pavement," Texas State Department of Highways and Public Works (Report No. 604-1) District 2, July 1975.

18. Lindley, B. R., "Cold Recycling of Asphalt Concrete Pavement," Texas State Department of Highways and Public Transportation (Report No. 613-1) District 8, October 1975.

19. Cannesa, W., "Cold Recycling of Asphalt Pavements - On Site and Off-Site," Golden Bear Division, Witco Chemical Corp., Oildale, California, 1979.

20. Schmidt, R. S., "A Practical Method For Measuring the Resilient Modulus of Asphalt Treated Mixes," Chevron Asphalt Company, Emeryville, California, January 1982.

21. Kari, W. J., Santucci, L. E., Coyne, L. D., "Hot Mix Recycling of Asphalt Pavement," Chevron Asphalt Company, Emeryville, California, February 1979.

22. Scrimsher, T., "Investigation of Distress in a Recycled AC Mix," (a memo to file report), California Department of Transportation, Sacramento, 1982.

23. Smith, Roger, "Laboratory Testing of Fabric Interlayers for Asphalt Concrete Paving," California Department of Transportation, Sacramento, California, 1984.

24. California Test 377 - "Method of Test For Determining the Percent and Grade of Recycling Agent to Use For Hot Recycling of Asphalt Concrete," TransLab, Sacramento, California, 1982.

25. California Test 378 - "Method of Test For Determining the Percent and Grade of Recycling Agent to Use for Cold Recycling of Asphalt Concrete," TransLab, Sacramento, California, 1982.

26. California Test 379 - "Method of Determining Asphalt Content of Bituminous Mixtures by Use of the Troxler Nuclear Gage (Model 3241)," TransLab, Sacramento, California, 1984.

27. Doty, R. N., Scrimsher, T., "Recycling Asphalt Concrete on Interstate 80," California Department of Transportation, FHWA-CA-TL-79-08, 1979.

28. Scrimsher, T., Recycling Asphalt Concrete on State Rte. 36, California Department of Transportation, FHWA-CA-TL-81-03, 1981.

29. Reese, R., Predoehl, N. H., "Evaluation of Rejuvenated Asphalt Aging Rate Relative to Paving Asphalt," California Department of Transportation, Sacramento, February 1986.

30. Alexander, M., "Placement of CTB on Project 02-114614-02-Sis-97-17.1/23.0," Memo To File, California Department of Transportation.

31. Soil Cement Laboratory Handbook, Portland Cement Association (PCA), Skokie, Illinois, 1971.

32. Christman, Robert, Pavement Resource Managers, Inc., "Recycling Bituminous Concrete Pavements Containing Petromat," Phillips Fibers Corporation, Greenville, South Carolina, February 15, 1981.

33. Brown, Elton R., "Insuring Quality in Hot Mix Recycling," U.S. Army Engineer, Waterways Experiment Station, Vicksburg, MS, January 1982.

34. Kennedy, T.W., Roberts, F. L., "Quality Assurance Considerations in Recycled Asphalt Mixture Design," University of Texas at Austin, January 1982.

35. Zuehlke, G. H., "The Design of Mixture Proportions For Recycled Bituminous Paving Mixtures," State of Wisconsin, Division of Highways and Transportation Facilities, Madison, Wisconsin, October 1981.

36. Watkins, R. O., Scrimsher, T., "Cold Recycling of Asphalt Concrete," California Department of Transportation, Presented at the 33rd Annual California Transportation Public Works Conference, April 1981.

37. Potts, C. F., "Insuring the Quality of Recycled Asphalt Concrete," State of Florida, Department of Transportation, Grainesville, Florida, August 1981.

38. Pavlovich, R. D., "A Comparison of Properties of Cold Mixed Emulsified and Hot-Mixed Asphalt Mixtures," (Part I and II) Engineers Testing Laboratories, Inc., Phoenix, Arizona, January 1981.

39. Goodsall, G. D., "In-Situ Recycling of Asphalt Wearing Courses in the UK," Department of Environment, Department of Transport, Supplementary Report 675, Crowthorne, Berkshire, England, 1981.

40. Beaty, R. W., "Hot Process Recycling of Asphalt Pavement Materials State of The Art," Barber Greene Co., Alvora, Illinois, May 1978.

41. Bernard, D. A., "Report on State of The Practice of Hot Mix Recycling," Federal Highway Administration, Washington, D.C., June 1982.

42. Little, D., Epps, J., Homgreen, R., "Cold Recycling: Design," Texas A&M, Rural and Uban Roads Article, March 1980.

43. National Cooperative Highway Research Program Synthesis of Highway Practice No. 54, "Recycling Materials For Highways, Washington, D.C., 1928.

44. Kallas, B. F., "Flexible Pavement Mixture Design Using Reclaimed Asphalt Concrete," The Asphalt Institute, College Park, Maryland, FHWA-RD-84-088.

45. Tanski, J. H., Hahn, K. C., "Recycling Reclaimed Asphalt Pavement," New York State Department of Transportation, State Campus, Albany, New York.

46. Transportation Research Board, "Proceedings of The National Seminar on Asphalt Pavement Recycling," National Academy of Sciences, Washington D.C., 1980 (Research Record No. 780).

47. Israel, R. W., "Soil Stabilization and Cold-Mix Recycling," BOMAG-AMCA INTERNATIONAL, Springfield Ohio, 1982.

48. Anderson, D. I., Peterson, D.E., Wiley, M. L., Betenson, W. B., "Evaluation of Selected Softening Agents Used in Flexible Pavement Recycling," Utah Department of Transportation, Salt Lake City, Utah, April 1978.

49. Santucci, L. E. Kari, W. J., "Hot Mix Recycling: Equipment Construction, Design, Results," Chevron Asphalt Co., Technical Paper Number 179, 1981.

50. Davidson, D. D., Canessa, W., Escobar, S. J., "Recycling of Substandard or Deteriorated Asphalt Pavements - A Guideline For Design Porcedures," Witco Chemical Golden Bear Division, Bakersfield, California.

51. Canessa, W., "Rejuvenating Asphalt Pavements," Consulting Engineer, Bakersfield, Calfiornia 1985.

APPENDIX - A

TEST PROCEDURES

DEPARTMENT OF TRANSPORTATION
DIVISION OF ENGINEERING SERVICES
Office of Transportation Laboratory
P. O. Box 19128
Sacramento, California 95819

California Test 377
August 1984

METHOD OF TEST FOR DETERMINING THE PERCENT AND GRADE OF RECYCLING AGENT TO USE FOR HOT RECYCLING OF ASPHALT CONCRETE

A. SCOPE

This procedure is used to determine the percent and grade of recycling agent to use for recycled asphalt concrete when the Hot Central Plant method of recycling is used.

B. APPARATUS

1. Equipment as described in California Tests 202, 304, 310 and 366.

C. MATERIALS

1. Recycling Agents

D. PRELIMINARY ESTIMATE OF RECYCLING AGENT GRADE AND AMOUNT

1. Salvaged Asphalt Concrete

Trim the samples of aged asphalt concrete so that only the portion to be recycled remains. Determine the asphalt content and after-extraction aggregate gradation of this asphalt concrete in accordance with Calif. Tests 310 and 202. Then select a gradation for the new aggregate to be added to the salvaged asphalt concrete that will provide whatever gradation adjustment is needed so that the gradation of the blend conforms to the final AC aggregate gradation selected for the project.

2. Viscosity of Aged Asphalt

Provide a representative sample of the asphalt concrete to be recycled (3500 grams minimum) to TransLab in Sacramento. Request that the aged asphalt physical properties be determined via the Abson Recovery Test (Calif. Test 380) with the viscosity reported in centipoise.

3. Recycling Agent*

a. Amount of total binder—Using the blended (salvaged + virgin) aggregate gradation selected for the recycled mix, determine the approximate total bitumin ratio (ABR) by use of the following formula:

$$ABR = \frac{4R + 7S + 12F}{100}$$

where: R = % retained on the #8 sieve
S = % passing the #8 sieve and retained on the #200 sieve
F = % passing the #200 sieve

b. Calculate the amount of aged asphalt "0" present in the total combined mix as follows:

0 = (% Ext.) (% salvaged AC in Recycled Mix)

c. Amount of recycling agent (% RA)— Subtract the amount of aged asphalt in the total mix (0) from the ABR. The remainder is the estimated amount of recycling agent required (RA).

d. Grade of recycling agent: Using Chart I,

1) Locate the viscosity of the aged asphalt (Abson recovery data) on Scale A.
2) Connect this point with the various paving asphalt and recycling agent viscosities on Scale C (draw straight lines diverging from the point on Scale A).
3) Calculate the percent of recycling agent or new asphalt that will be in the recycled mix as follows:

$$RAB = \frac{RA}{ABR} \times 100$$

where: RAB = recycling agent in blend, %
RA = recycling agent from "c" above, %
ABR = total binder content from "a" above, %

4) Locate % RAB on scale "B" of Chart I.
5) Draw a vertical line to intersect each of the horizontal lines representing the AR grades of asphalt.
6) Note the intersection of the perpendicular line from scale B and the desired AR grade viscosity. Select the recycling agent grade represented by the diagonal line closest to this intersection.

* Form No. TL 312 to be used as a work sheet.

E. RECYCLING AGENT GRADE AND AMOUNT RECOMMENDATION

1. Weigh out a moisture-free representative sample of salvaged AC equivalent to the amount (based upon a 2400 gram sample) proposed for the recycled mixture. For example, a 50/50 mix would require 1200 grams, a 70/30 mix would require 1680 grams, etc. This is the "wet" weight.

2. Determine the dry aggregate weight of the salvaged AC per batch:

$$\text{dry wt.} = \frac{\text{wet wt.}}{100 + \%\ \text{asph. ext.}}$$

3. Weigh out a moisture-free representative sample of virgin aggregate (of the gradation selected) equivalent to the amount (based on a 2400 gram sample) proposed for use in the recycled mixture.

4. Combine the salvaged AC and virgin aggregate in one large pan and heat this material in a 325°F oven for 2 ± 1 hours.

5. Remove the sample from the oven and immediately add the required amount of recycling agent per Section D.3.c.

6. Mix until well coated (hand or mechanical mixing).

7. After mixing, remove two 600 ±50 gram samples by quartering using a 1" riffle splitter and measure the binder content and aggregate gradation of each per Calif. Test 310 & 201. The average of the two tests must show that the binder content is ±0.2% of the desired amount and the gradation must be within ±5 points on any sieve. Retain the remaining 1200 grams.

8. Prepare three additional samples using 1200 grams for each sample. Vary the amount of recycling agent above and below the % RA per D.3.c using 0.5% increments based upon dry aggregate weight (usually 1 above and 2 below).

9. Transfer the four 1200 gram samples of recycled mix (one from No. 7 above and three from No. 8 above) to flat pans 11 in. x 7 in. x 1 in. and cure for a minimum of 15 hours in a 140° ± 5°F oven.

10. Fabricate four briquettes per Part II of Calif. Test 304.

11. Measure the stability of the four briquettes per Calif. Test 366.

12. Determine the optimum % RA per Calif. Test 367.

13. After establishing the optimum % RA, recalculate the % RAB.

14. Locate this optimum % RAB on scale "B" of Chart I.

15. Draw a vertical line to intersect the viscosity curve for the recycling agent used in the test. This point of intersection must be within one grade of the blend viscosity selected for design (±). If it is not, select another grade of recycling agent and repeat the design testing. If the newly selected grade of recycling agent does not provide blend consistency within one grade of the selected viscosity, then the material should be designated as a poor risk for recycling.

F. EXTRACTION CALIBRATION CURVE

Prepare an asphalt extraction calibration curve of final recycled mix in accordance with TM310.

G. PRECAUTIONS

1. Use leather gloves when handling hot material.

H. REPORTING OF RESULTS

1. Report gradation of:
   a. Salvaged AC
   b. "New" aggregate
   c. Recycled mix

2. Report ratio used (salvaged AC to new aggregate) such as 50/50, 60/40, 70/30, etc.

3. Report binder used:
   a. Amount recommended
   b. Grade recommended
   c. Source used

4. Report stability and specific gravity of test specimen at recommended RA content.

5. Report specific gravity of RA used.

6. Report extraction calibration curve.

7. Use Test Card, Form No. TL-302, for reporting of test data.

I. NOTE

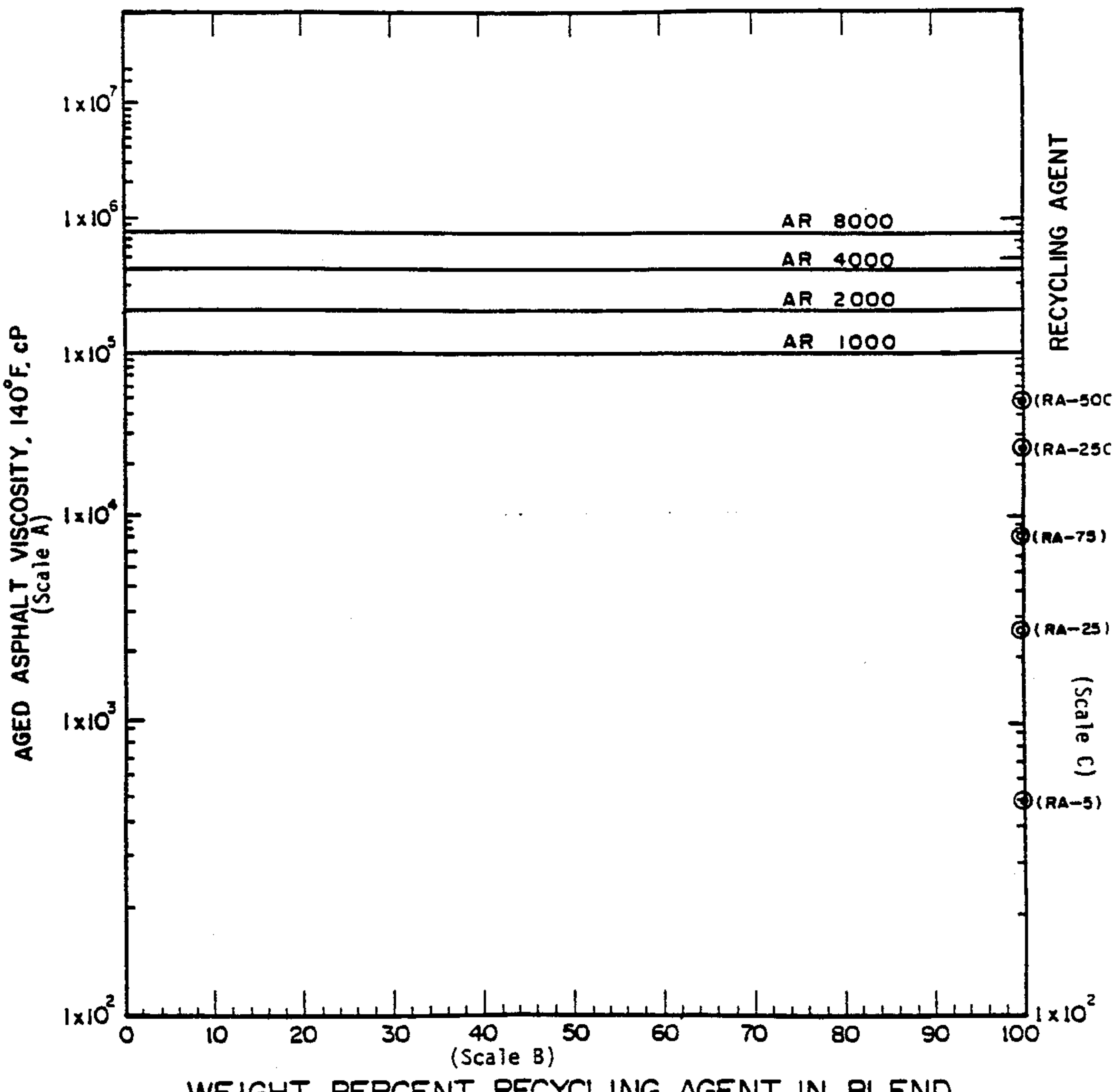
If the stabilometer values are all less than the desired 35 for Type B or 30 for Type C and ⅜" max. Type B, select the next heavier grade of recycling agent and repeat the testing.

End of Test

REFERENCES

California Tests 202, 308, 310, 366 and 367

CHART 1



TO USE: Draw a straight line connecting viscosity of aged asphalt with viscosity of recycling agent. Draw a vertical line up from the percent recycling agent in blend. The two lines intersect at predicted approximate viscosity of the recycled asphalt.

NOMOGRAPH FOR VISCOSITY

Form No. TL-314 (Rev 4/84)

TEST REPORT NO.______

Location: Dist.______ Co.______ Rte.______ P.M. ______

Contract No. ______

COLUMN			1	2	3	4
DATA			PAV'T. TO BE RECYCLED (MEASURED)	DESIGN CALC.	DESIGN RECOMM.	RECYCLED PAVEMENT (MEASURED)
DATE:						
(A) Asphalt Content, %				—	—	
(B) Asphalt Demand	(1) O		—			
	(2) (V) (V_a)		—			
	(3) (B_1 − A) (T) + B_2		—			
(C) Stab. Value Calif. T.M.366	Compacted @ 230°F Tested @ 140°F		—	—		
	Compacted @ 140°F Tested @ 140°F		—	—		
(D) Sp. Gr.	Calif. TM 308C	(1) Compacted @ 230°F Tested @ 140°F	—	—		
		(2) Compacted @ 140°F Tested @ 140°F	—	—		
	(3) Theoretical Max. Sp. Gr. (ASTM) D-2041		—	—		
(E) % Voids $\left(100 - \frac{D_1 \text{ or } D_2}{D_3}\right)$			—	—		
(F) Penetration @ 77°F						
(G) Viscosity @ 140°F, cP						
(H) Aggregate Gradation: R, retained #8, %						
S, passing #8, retained #200, %						
F, passing #200, %						

NOTES:

Calculate $B^1 = \frac{4R + 7S + 12F}{100}$ = ______ Emulsion = $\frac{B^1}{.60}$ = ______%

Grade of recycling agent used ______

COMMENTS:

Virgin aggregate asphalt content is based on AR Grade 4000 if a recycling agent is to be used as a binder.

(B) Asphalt Demand

O = 100% Salv. A.C.

V = % of Virgin Agg.

V_a = Binder Content For 100% Virgin Agg.

T = % of Salvaged

Form No. TL-312 (Rev. 4/84)

DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
Office of Transportation Laboratory
P. O. Box 19128
Sacramento, California 95819

California Test 378
November 1, 1983

METHOD OF TEST FOR DETERMINING THE PERCENT AND GRADE OF RECYCLING AGENT TO USE FOR COLD RECYCLING OF ASPHALT CONCRETE

A. SCOPE

This procedure is used to determine the percent and grade of recycling agent to use for recycling asphalt concrete when the cold method of recycling is used.

B. APPARATUS

1. A jaw crusher which can be adjusted to produce material passing the No. 4 sieve. A sledge hammer may be used to reduce oversize particles enough to permit the material to be fed into the crusher.
2. Hot asphalt extractor as described in California Test 310.
3. Two ovens, one capable of maintaining a temperature of 140° ± 5°F with provision for free circulation of air through the oven and another capable of maintaining a temperature of 300° ± 9°F. A microwave oven may be used in lieu of the 300°F oven.
4. Balance, 5 kg. capacity; accurate to 1 gram.
5. Sieves, U.S. Standard sizes; 1 in., ¾ in., ½ in., ⅜ in., Nos. 4, 8, 16, 30, 50, 100, 200.
6. Sample splitter for aggregates, 1 in. riffle type or equal.
7. Pans, 10 in. diameter, 2 in. deep.
8. Pans, 11 in. × 7 in. × 1 in. deep.
9. Trowels, small pointed.

C. MATERIALS

1. Emulsified recycling agents.

D. PREPARATION OF SAMPLES

1. Gradation
   a. Pavement Cores or Chunks
      1) Trim samples so that only that portion designated for recycling remains.
      2) Prepare an 800 gram representative sample of the proposed recycling mix.
         a) Determine the asphalt content using Calif. Test 310.
         b) Determine aggregate gradation after extraction using Calif. Test 202.
      3) Crush the remaining material proposed for recycling to conform (approximately) to the following gradation prior to extraction:

Sieve Size	*% Passing*
1"	100
¾"	*
⅜"	*
#4	70% of the amount passing the #4 sieve for the after-extraction grading.

* Determine by drawing a straight line between plotted points for the 1" and #4 sieves as illustrated on Figure 1.

   b. Pulverized Field Samples
      1) Prepare field samples representative of the material processed by the contractor (milling and/or crushing) and ready for field mixing as follows:
         a) Dry to a constant weight in an oven (maximum temperature 140°F).
         b) Remove from oven and cool to room temperature.
         c) Quarter out 2000 ± 1 grams.
         d) Determine and record the gradation (% passing) by hand sieving through the following sieves:
            1½"
            1" *
            ¾"
            ⅜"
            #4

2. Viscosity of Aged Asphalt
   a. Prepare a 3500 gram sample representative of the material to be recycled and send to TransLab in Sacramento. Request that the asphalt physical properties be determined via the Abson Recovery Test.
3. Recycling Agent—Amount and Grade.
   a. Determine approximate total bitumen requirement (ABR) using the formula:

$$ABR = \frac{4R + 7S + 12F}{100} \times 1.1$$

where, after extraction: R = %retained #8
S = % passing #8 and retained #200
F = % passing #200

Record data on Form No. DH-TL-312

* When preparing the stabilometer test, always scalp so that 100% passes the 1" sieve.

b. Determine the amount of recycling agent to add by subtracting the asphalt content of the old pavement from the ABR. Divide the remainder by .60 to obtain the percent of *emulsified* recycling agent to add.

c. Determine the amount of recycling agent (%) in the final blend (asphalt and recycling agent) by dividing the *residual* amount of recycling agent to be added by the total binder content.

d. Using the nomograph for viscosity (Form 314), plot the viscosity of the aged asphalt (use centipoise) on the left viscosity scale and connect that point with lines extending to points representing the viscosities of the residues for the various emulsified recycling agents on the right vertical scale, thereby creating a family of curves.

e. On the nomograph, locate the percent of recycling agent in the blend on the lower horizontal scale and draw a vertical line from this point.

f. At the intersection of the above established vertical line and the horizontal viscosity line for AR-4000, note the closest recycling agent curve. Select this grade of recycling agent to begin testing.

4. Prepare the test specimens for the stabilometer evaluation as follows:

a. Prepare six 1200 gram samples using material prepared in accordance with D 1. a. or D 1. b.

b. Save one sample for determining maximum specific gravity (ASTM D-2041) and one sample for future testing if needed.

c. Dry four samples to a constant weight in a 140°F oven.

d. Remove the four samples from the oven and cool at room temperature for 2 hours ± 30 minutes.

e. Add 2.0% water to each sample by dry weight of the mix and thoroughly hand mix.

f. To one sample, add the amount of emulsion calculated in Paragraph 3b and thoroughly hand mix (aggregate, emulsion and mixing at room temperature, 75 ± 5°F).

g. Add lesser and greater amounts of emulsion in 0.8% increments. General practice is to increase the content on one sample and decrease it on two samples. Mix each sample thoroughly after the addition of the emulsion.

E. CURING

1. Place in standard curing pans (7" × 12 " × 1") and cure at 140°F for 16 ± 1 hours.

F. FABRICATION OF THE STABILOMETER TEST SPECIMENS

1. Prepare compaction mold and mold holder by placing in a 140°F oven for 30 minutes prior to use. If several samples will be compacted in succession, the mold holder may be used after the first preheating without additional heating.

2. Place mold in mold holder and this assembly into position in the mechanical spader. (If a mechanical spader is not available, proceed to paragraph "8".) Place a metal shim ¼" thick, approximately ¾" wide and 2½" long under the mold adjacent to the portion of the mold holder that extends up into the mold. Place a 4" diameter cardboard disk into the mold on top of the mold holder base.

3. Weigh out sufficient mix to provide a specimen between 2.40" and 2.60" in height for the stabilometer test.

4. Separate the coarse and fine material by screening the mix through a ½" sieve onto a flat metal scoop.

5. Arrange the separated material into two parallel rows across the width of the scoop with the finer material closest to the scoop handle.

6. Introduce the mix onto the feeder belt of the mechanical spader, exercising care so as not to disturb the size arrangement effected on the metal scoop.

7. Start the mechanical spader and operate until all of the material has been introduced into the compaction mold. Proceed to step 9.

8. In lieu of the mechanical spader described above, a specially constructed feeder trough 4 in. wide and 16 in. long may be used for introducing the mix into the mold. Thoroughly mix and disperse the heated material on the trough (which has also been preheated to approximately the compaction temperature to be used) to insure a uniform sample when transferred to the mold. Place the mold in position in the mold holder and place a 4 in. diameter cardboard disk into the mold on top of the mold holder base.

Use a paddle, shaped to fit the trough, to push one-half of the material into the mold. Rod the material 20 times in the center of the mass and 20 times around the edge with a bullet nosed steel rod ⅝ in. diameter, 16 in. long. Then push the remainder of the sample into the mold and repeat the rodding procedure. Perform these operations as rapidly as possible to prevent cooling of the sample. If two feeder troughs are available, the work can be expedited by preparing another sample while one is being compacted. The extra trough containing the next sample is kept in the oven until ready for compaction.

9. Place mold holder containing the mix and mold into position in the mechanical compactor.

10. Start the compactor and adjust the air pressure so 250 psi will be exerted by the tamper foot. Keep the tamper foot hot enough to prevent the mix from adhering to it.

11. Apply approximately 20 tamping blows at 250 psi pressure to accomplish a semi-compacted condition so the mix will not be unduly disturbed when the full load is applied. The exact number of blows to accomplish the semi-compaction shall be determined by observation. The number of blows may vary between 10 and 50, depending upon the type of material.

12. Remove the ¼ in. shim and release the tightening screw sufficiently to allow approximately ⅛ in. side movement under load. Then raise the compaction pressure to 500 psi and apply 150 tamping blows to complete the compaction in the mechanical compactor.

13. Apply a total static leveling-off load of 1250 lbs. in the testing machine at a head speed of .05 in. per minute with the bottom of the sample in contact with the lower platen of the press. Release the applied load immediately.

14. Measure the height of the test specimen to the nearest 0.01 in. and record for later use.

G. TESTING

1. Stabilometer Test
   a. Test for stabilometer value at 140°F in accordance with Calif. Test 366.
2. Specific Gravity and Voids
   a. Use the stabilometer test specimen and determine the specific gravity of the briquette using Method A of Calif. Test 308.
   b. Place a 1200 gram sample (from D 4. b.) of salvaged AC in a container as required and determine the salvaged AC specific gravity using ASTM Test Procedure D-2041.
   c. Calculate the void content of the test specimen as follows:

$$\text{Max.Sp.Gr.} = \frac{100 + \%\ \text{Asphalt Residue}}{\dfrac{100}{\text{Salv.AC Sp. Gr.}} + \dfrac{\%\ \text{Asphalt Residue}}{\text{Sp.Gr.Asph.}}}$$

$$\text{Relative Density} = \frac{\text{Sp.Gr. Briq.}}{\text{Max.Sp.Gr.}}$$

$$\text{Percent Voids} = 100 - \text{Relative Density}$$

H. RECOMMENDATION

1. Optimum Bitumen Content (OBC). Recommend the highest emulsion content that provides a specimen with the desired stabilometer value *, no evidence of surface flushing or bleeding, and a minimum of 4% voids. Slight flushing is considered as no flushing.

* Traveled way stabilometer value = 30 min.
Shoulder stabilometer value = 25 min.

I. CORRECTION OF GRADE OF RECYCLING AGENT

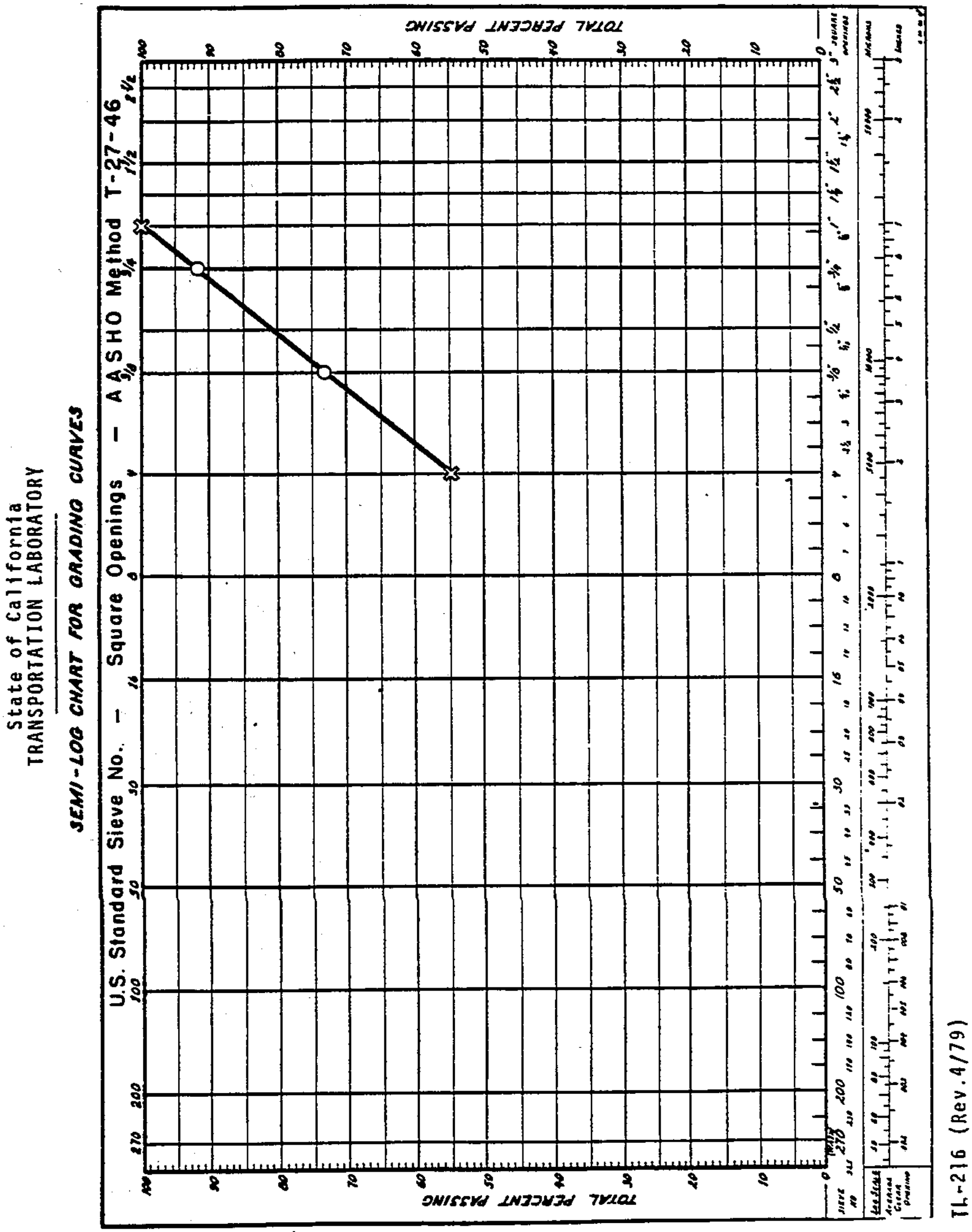
1. Replot the final binder content data on the viscosity nomograph. If this results in the need to use a grade of recycling agent different than the one tested, retest using the recommended amount with the newly designated recycling agent.

J. REPORTING OF RESULTS

1. Use Form TL 302 for recording and reporting test data.

2. Report:
   1) Asphalt extraction
   2) Extracted grading
   3) Grading prior to extraction
   4) Grade of recycling agent to use
   5) Amount of recycling agent (OBC)
   6) Voids at OBC
   7) Viscosity used as a design basis (1000, 2000, 4000 or 8000)

End of Text (3 pages) on Calif. 378


State of California
TRANSPORTATION LABORATORY
SEMI-LOG CHART FOR GRADING CURVES
U.S. Standard Sieve No. — Square Openings — AASHO Method T-27-46
TOTAL PERCENT PASSING
TL-216 (Rev.4/79)

TEST REPORT NO.______

Location: Dist.______ Co.______ Rte.______ P.M. ____________

Contract No. ________

COLUMN			1	2	3	4
DATA			PAV'T. TO BE RECYCLED (MEASURED)	DESIGN CALC.	DESIGN RECOMM.	RECYCLED PAVEMENT (MEASURED)
DATE:						
(A) Asphalt Content, %				—	—	
(B) Asphalt Demand	(1) O		—			
	(2) (V) (V_a)		—			
	(3) (B_1 − A) (T) + B_2		—			
(C) Stab. Value Calif. T.M.366	Compacted @ 230°F Tested @ 140° F		—	—		
	Compacted @ 140°F Tested @ 140° F		—	—		
(D) Sp. Gr.	Calif. TM 308C	(1) Compacted @ 230°F Tested @ 140°F	—	—		
		(2) Compacted @ 140°F Tested @ 140° F	—	—		
	(3) Theoretical Max. Sp. Gr. (ASTM) D-2041		—	—		
(E) % Voids $\left(100 - \frac{D_1 \text{ or } D_2}{D_3}\right)$			—	—		
(F) Penetration @ 77°F						
(G) Viscosity @ 140°F, P						
(H) Aggregate Gradation: R, retained #8, %						
S, passing #8, retained #200, %						
F, passing #200, %						

NOTES:

Calculate $B^1 = \frac{4R+7S+12F}{100} \times^{1.1} =$ ________ Emulsion = $\frac{B^1}{.60}$ = ________%

Grade of recycling agent used ______________________________

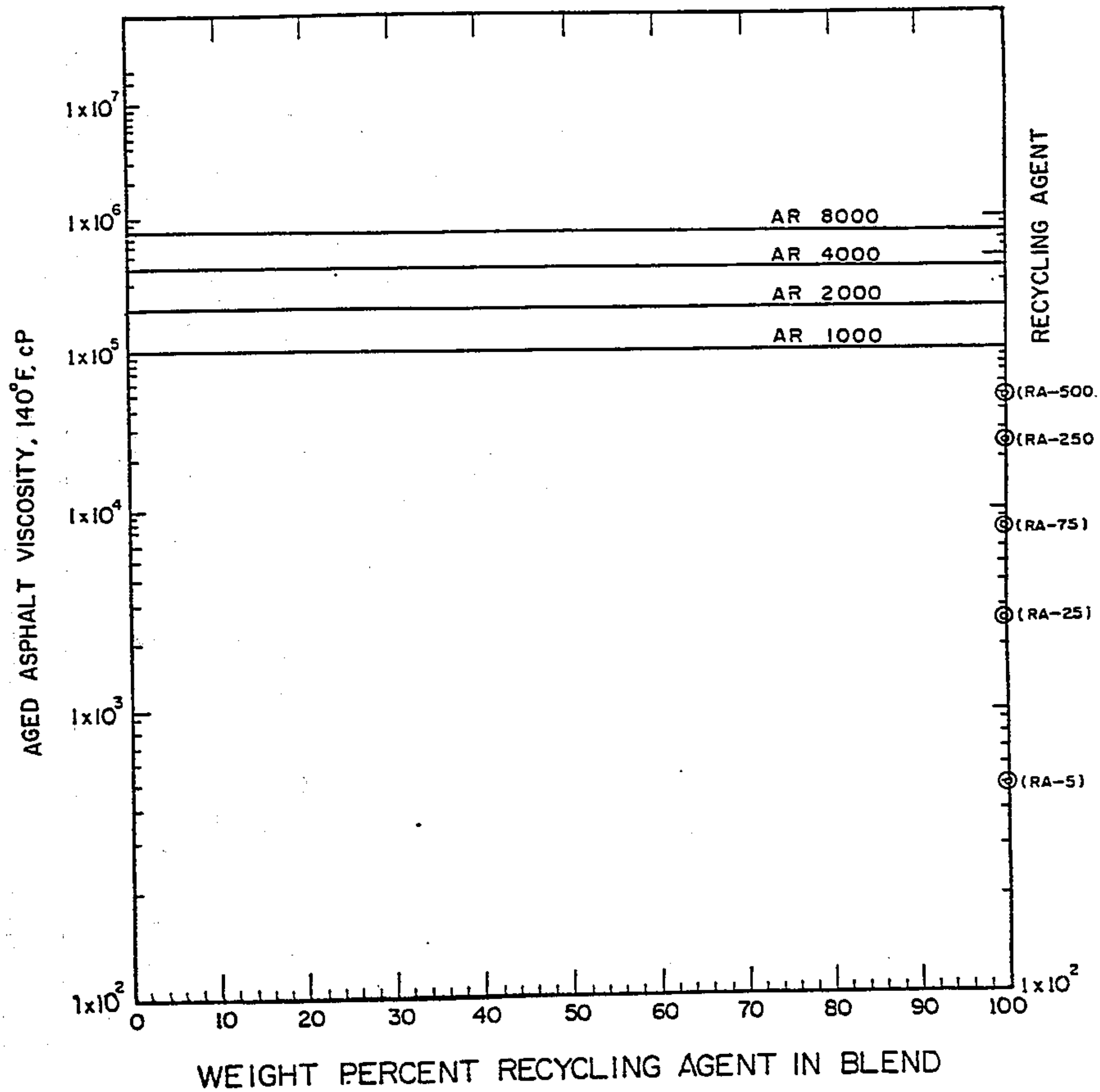
COMMENTS:

Virgin aggregate asphalt content is based on AR Grade 4000 if a recycling agent is to be used as a binder.

(B) Asphalt Demand

O = 100% Salv. A.C.
V = % of Virgin Agg.
V_a = Binder Content For 100% Virgin Agg.
T = % of Salvaged

Form No. DH-TL-312



TO USE: Draw a straight line connecting viscosity of aged asphalt with viscosity of recycling agent. Draw a vertical line up from the percent recycling agent in blend. The two lines intersect at predicted approximate viscosity of the recycled asphalt.

NOMOGRAPH FOR VISCOSITY

Form No. DH TL-314

DEPARTMENT OF TRANSPORTATION
DIVISION OF FACILITIES CONSTRUCTION
Office of Transportation Laboratory
P.O. Box 19128
Sacramento, CA 95819

California Test 379
January, 1985

METHOD B—HOT RECYCLED BITUMINOUS MIXTURES

PART I: METHOD OF PREPARATION OF SAMPLES FOR GAGE CALIBRATION

A. SIZE

The size of the sample will be the amount required to fill the stainless steel pans (Apparatus—Item B2). This will vary depending on the specific gravity of the aggregate and generally will be between 6000 and 8000 grams; therefore, 8000 grams has been selected as the standard weight to batch for the preparation of the "blank" (sample of RAP [1] and virgin aggregate without the addition of new asphalt). The actual weight will be as outlined in paragraph "B".

B. PREPARATION OF "BLANK" AGGREGATE SAMPLE

1. Batch two samples of virgin aggregate using the gradation and source selected for the project.

2. Batch two samples of RAP representing the material to be used on the project.

Note: Approximately 8000 grams of material will be required to fill the gage pan, however, to minimize drying time, it is advisable to batch smaller samples, thus the following weights should be used for batching:

For a 4000 gram total sample (dry)

Recycle Mix Formula	*RAP*	*Virgin Aggregate*
70/30	2800	1200
60/40	2400	1600
50/50	2000	2000

To compensate for moisture, add 25 grams of the passing #4 fraction to each batch.

3. Use a 300°F oven and dry each batch to a constant weight (1.0 gram loss or less in 20 minutes) or for 48 hours [2], whichever is less. Samples removed from the oven for purposes of checking weights must be permitted to cool at room temperature for 15 minutes prior to weighing.

4. After samples are dry, combine into two 4000-gram batches according to the selected job mix formula and bring each back to 300°F.

5. Remove from oven and place one combined 4000-gram sample into the Hobart mixer (Figure 1) and mix for 3 minutes or until thoroughly mixed. Repeat mixing for second 4000-gram sample.

HOBART MIXER

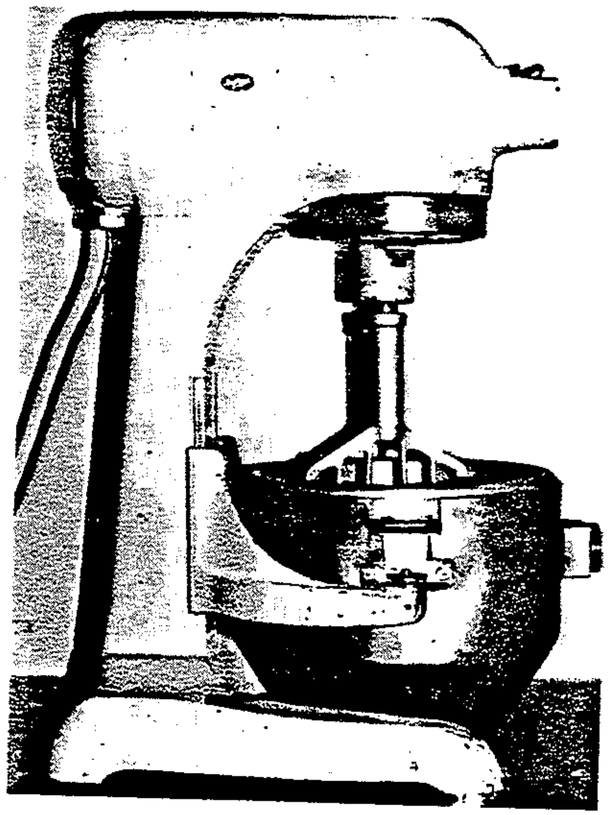


FIGURE 1

6. Remove each batch from the Hobart mixer, place in suitable container, and return to 300°F oven.

7. Prepare samples for fabrication and testing in the gage as follows:

   a. Remove a sample pan from the oven when the mix reaches a minimum temperature of 230°F.

   b. With the use of a scoop, place enough mix from the pan immediately into a tared preheated steel pan until it's just over half full (Item B2) (Figure 2).

   c. Using a ⅜" diameter steel rod, rod 20 strokes (around the edges and down the center).

---

[1] Reclaimed Asphalt Pavement

[2] In the case of absorbtive aggregates (Km values of 1.8 or higher), the 48-hour drying time in a 300°F oven may be required.

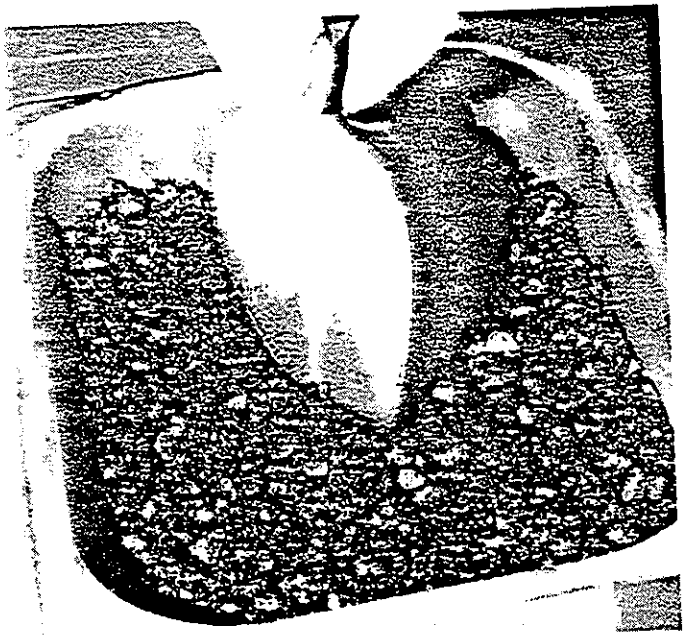


FIGURE 2

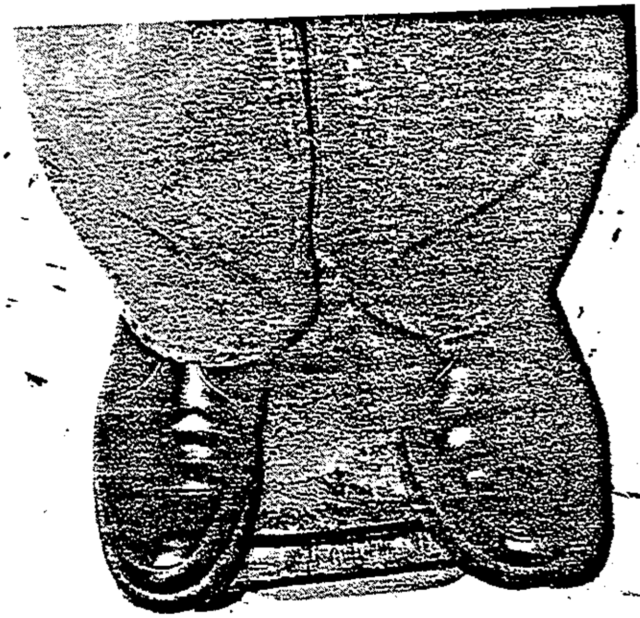


FIGURE 3

d. Remove a second pan of mix from the oven and continue filling the pan until the aggregate (mix) is approximately ½" *above* the pan rim. (Figure 3).

e. Using a ⅜" diameter steel rod, rod 20 strokes (around the edges and down the center).

f. Place a straightedge firmly across the top rim of the pan and, using a sawing motion, strike off the surface of the sample so it is flush with the pan top.

g. Weigh the pan and sample to the nearest 1.0 gram.

h. Calculate the net weight (designate as *Wo*) by subtracting the pan tare weight from the total weight.

i. Store pan and contents for future reference of gage calibration.

C. PREPARATION OF AC MIXTURE FOR GAGE CALIBRATION

1. General

Obtain an average value for the asphalt content of the RAP by measuring (using Calif. TM's 310 or 362) the asphalt content of samples taken from 10 different locations. Apply a correction factor by adding 0.2% to this average value to compensate for sampling and extraction error.

2. RAP

The RAP stockpile will be periodically checked for asphalt content using the gage. This is done by adding a small amount of new asphalt to one of the calibration samples and the test sample. The preparation procedure is as follows:

a. Obtain a 32,000± gram (approximately 70 lbs) sample and "split" into eight 4000 gram samples for establishing the endpoints of a calibration curve.

b. Use a 300 ± 10° oven or a microwave oven to dry the test samples to a constant weight (1.0 gram loss or less in 20 minutes).

c. Calculate dry aggregate weight of sample using the average asphalt content established for the RAP.

$$\text{DRY WT.} = \frac{\text{WET WEIGHT} \times 100}{100 + \%\ \text{ASP. EXT.}}$$

d. Add no new asphalt to one sample and 2.0% (by dry weight of aggregate) to the other sample (use the grade of asphalt designated for the project). Record asphalt contents as related to average value obtained in C-1.

e. Individually place each sample (must be a minimum of 230°F.) in the Hobart mixer (Figure 1) and mix for 3 minutes or until thoroughly mixed. Place mixed samples in 300°F oven.

f. Fabricate calibration sample for test as outlined in Part I–B-7 (Record net weight in part h as Wp for RAP).

g. Fabricate calibration samples with 2% new asphalt added as follows:

g-1. Remove a sample pan from the oven when the mix reaches a minimum temperature of 230°F.

g-2. Using a scoop, place approximately ½ of Wp (obtained from f above) immediately into a tared preheated steel pan (Item B-2).

g-3. Using a ⅜" diameter bullet pointed steel rod, rod 20 times (around the edges and down the center of the pan).

g-4. Remove a second pan of mix from the oven and continue filling the pan until the mix is approximately ½" *above* the pan rim.

g-5. Using a ⅜" diameter bullet pointed steel rod, rod 20 times (around the edges and down the center of the pan).

g-6. Adjust mix net weight by adding or removing mix to equal Wp.

g-7. Place a plywood pressing board on the mix and press down until board touches the pan rim (usually accomplished by standing on the pressing board—Figure 3).

g-8. Store pan and contents for future reference of gage calibration.

NOTE: Mix *must* be at least 230°F for proper fabrication. If the temperature drops below 230°F, reheat in a 300°F oven until hot enough to fabricate.

h. Proceed to Part II for method of calibration.

3. Recycled AC

After establishing the asphalt content of the RAP, prepare samples as follows:

a. Convert total sample weight to dry aggregate weight using the recycle formula 50/50, 60/40, etc., and the average asphalt content.

b. Add the amount of new asphalt or recycling agent required to prepare the calibration sample (1.0% below optimum and 1.0% above optimum [3]).

c. Refer to Method A paragraph C-3 for preparation of samples.

d. Proceed to Part II for method of calibration.

PART II: METHOD OF CALIBRATION OF GAGE

A. RAP

Use the asphalt contents from Part I-C-2-d.

1. Follow the procedure outlined in Part II, paragraph A of Method A.

B. RECYCLED AC

Use the asphalt contents from Part I-C-3-b.

1. Follow the procedure outlined in Part II, paragraph A of Method A.

PART III: MEASURING ASPHALT CONTENT

A. RAP

1. Obtain a representative 32,000 gram RAP sample.

2. Prepare material as follows:

a. Quarter out one 8000 gram sample.

b. Split into two 4000 gram samples.

c. Dry each sample to a constant weight @ 300° ± 10°F. or by use of a microwave oven.

d. After dry, add 1.0% new binder to each 4000 gram sample (same grade as used for calibration samples), based on dry weight of aggregate in sample and thoroughly mix in the Hobart Mixer.

e. Continue to paragraph "C-2" for preparation of test.

B. RECYCLED AC

1. Obtain a representative street sample (10,000 grams minimum).

C. PREPARE TEST SPECIMENS AS FOLLOWS:

1. Split out a 500 gram sample of the hot material and measure the moisture content per Calif. TM 370.

2. Using a scoop, place approximately ½ of Wp (Part I-C-2-f) for RAP or ½ of Wo (Part I-B-7-h) for recycled AC immediately into a tared preheated steel pan (Item B-2).

3. Using a ⅜" diameter bullet pointed steel rod, rod 20 times (around the edges and down the center of the pan).

4. Place additional mix into the pan until the mix is approximately ½" above the pan rim.

[3] Optimum obtained from Calif. TM 377

5. Using a ⅜" diameter bullet pointed steel rod, rod 20 times (around the edge and down the center of the pan).

6. Adjust mix net weight by adding or removing mix to equal Wp for the RAP or Wo for the recycled AC.

7. Place a plywood pressing board on the mix and press down until board touches the pan rim (usually accomplished by standing on the pressing board—Figure 3).

Note: Mix *must* be at least 230°F for proper fabrication. If the temperature drops below 230°F, reheat in a 300°F oven until hot enough to fabricate.

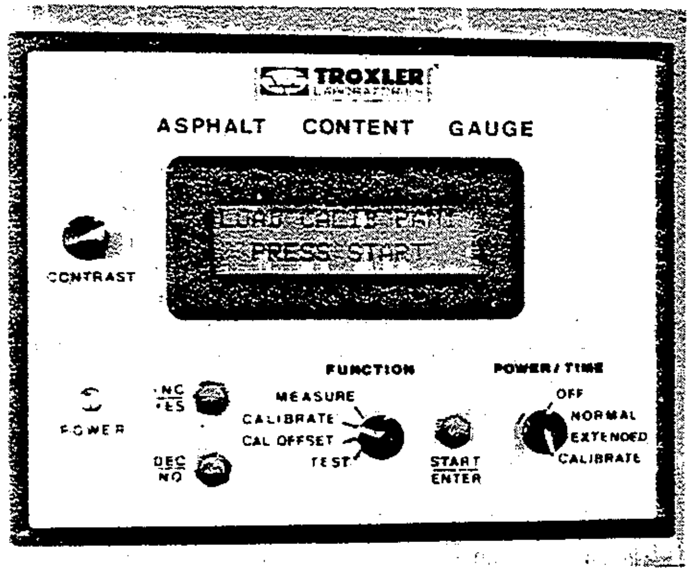


FIGURE 4

D. MEASURE ASPHALT CONTENT

1. The "Measure" function is the primary mode of operation of the 3241 Asphalt Content Gage (Figure 4). This mode of operation can only be entered after the 3241 has been calibrated by using the Manual Calibration Entry, New Calibration Entry or Calibrate routines. At the conclusion of the count time selected on the Power/Time switch, the results are displayed as follows:

$$\%AC = \emptyset\emptyset.\emptyset\emptyset$$
$$MC = \emptyset\emptyset\emptyset\emptyset$$

The %AC is the asphalt content of the sample derived from the MC (measure count). A count-down time is updated and displayed at the end of each minute to aid the operator.

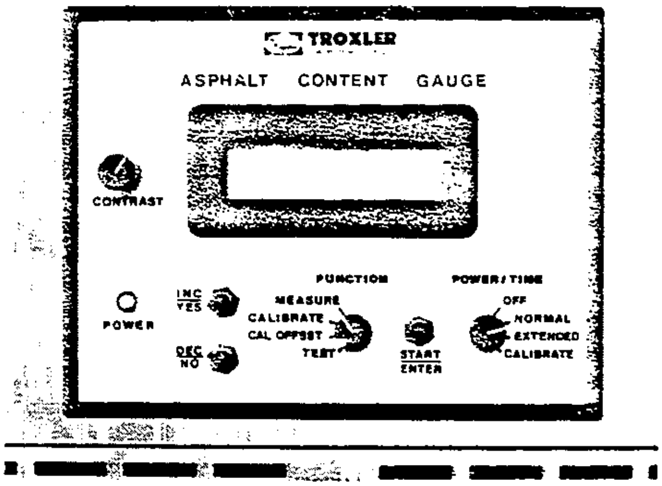


FIGURE 5

REFERRING TO FIGURE 5.

a. Rotate the "Power/Time" switch to the "Normal" position (Normal = 4 minutes).

b. Rotate the "Function" switch to "Measure". "Load Sample Pan/Press Start" will appear on the display.

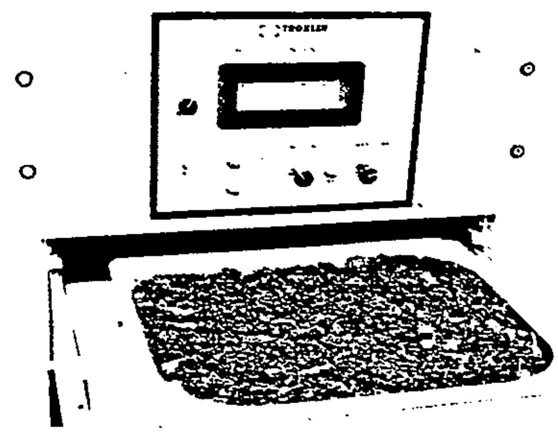


FIGURE 6

REFERRING TO FIGURE 6:

a. Insert a properly prepared pan of the sample mix into the drawer—close and latch the drawer.

b. Press Start/Enter button. "Counting T = 4 min." will appear on display.

c. Count will now continue automatically until four minutes have elapsed. At the conclusion of the time interval, the results appear as:

%AC = ∅∅.∅∅
MC = ∅∅∅∅*

d. Record %AC, MC and sample data.

e. Clear display window by pressing Start/Enter button—when machine is clear of data on sample just tested, display window will then read "Load Sample Pan/Press Start".

f. Remove sample from drawer and insert another properly prepared sample pan into the gage and repeat the sequence ("b" through "f").

g. Subtract the moisture content (%) as determined from Calif. TM 370 from the %AC displayed on the gage for each sample.

h. Subtract 1.0% (for asphalt added) from RAP test specimens.

4. Report the bitumen content on Form TL-302.

PART IV: PRECAUTIONS

1. The nuclear asphalt gage shall be operated in accordance with all safety methods and procedures as outlined by the manufacturer and radiation safety officer and Calif. TM 121.

2. Wear leather gloves when fabricating the specimens to avoid burns.

3. A check of the aggregate may be made by obtaining bin or belt samples and preparing and testing a new blank. A change in the count will alert the inspector to possible changes in pit conditions and/or retained aggregate moisture.

4. A change of the gage's location can have an effect on the calibration of the gage. Therefore, a new calibration must be completed if the gage is moved. The previous calibration samples can be used.

5. When compacting test specimens in steel pans fabricator should be holding on to something immovable, as pan tends to wobble or tilt when fabricators weight is applied.

6. Samples placed in the 300°F oven shall not be left for more than four hours (excluding drying time to remove moisture).

(11 pages) on Calif. 379

APPENDIX I

CALIBRATION INTERCEPT OFFSET (BLANK)

It is possible to change a calibration stored in the gauge or to set the gauge to an old calibration if the INTERCEPT (% asphalt for 0 count) and SLOPE (% asphalt per count) have been recorded or the Calibration Panl %AC/COUNT and Pan2 %AC/COUNT have been recorded.

There are three methods of altering the calibration currently stored in the gauge. These are: 1) direct alteration of intercept, 2) direct alteration of slope, and 3) indirect alteration of slope and intercept by changing the % asphalt assigned to one or both of the calibration samples. In most applications, the most common alteration is that of a direct change of the calibration INTERCEPT due to a change of moisture in the aggregate.

The 3241 "SLOPE/INTERCEPT" routine permits the modification of "SLOPE" or "INTERCEPT".

The value of INTERCEPT for each calibration should be recorded and compared with the %AC of a pan of dry aggregate. A sample of dry aggregate should be obtained each day to check the performance of the drier. The same weight of sample as was used in the initial calibration is placed in a sample pan, and a timed count in the CALIBRATE mode is taken on the sample. This %AC of the dry aggregate is compared with the %AC of the dry aggregate during the initial calibration. Using this data, the value of INTERCEPT is altered accordingly.

For example, during calibration, the dry aggregate had a %AC of 0.24. The *computed* gauge INTERCEPT was −5.23. The reason that the dry aggregate did not read 0.00 %AC is that the gauge response is not linear over this wide a range of asphalt content. Today, a CALIBRATE timed count in a sample of dry aggregate produced a %AC of 0.19, indicating that there is less moisture in the aggregate. Calculate the change in %AC using %AC = (%AC CALIB. AGG) − (%AC SAMPLE AGG) and New Intercept = (CALIB INTERCEPT) + %AC. Therefore, %AC = 0.24 − 0.19 = 0.05 AND, the "New Intercept" = −5.23 + 0.05 = −5.18 indicated a modified calibration causing the 3241 to operate as if no change in moisture or calibration had occurred.

The value of INTERCEPT is changed by rotating the FUNCTION switch to CAL OFFSET and using the following procedure:

1. When the FUNCTION switch is rotated to CAL OFFSET, the display should be "CALIB OFFSET/PROCEDURE *".
2. Press START/ENTER, and "SLOPE/INTERCEPT/OFFSET? YES/NO" is displayed.
3. Press INC/YES, and the gauge will display the currently stored calibration, "INTERCEPT = −5.23/INC/DEC ENTER/*".
4. Now the INTERCEPT may be adjusted to the correct value (−5.18) using the INC/YES or DEC/NO as appropriate. IT SHOULD BE NOTED THAT BECAUSE INTERCEPT IS NEGATIVE, THAT INC REDUCES THE MAGNITUDE OF INTERCEPT AND DEC INCREASES ITS MAGNITUDE.
5. Once the INTERCEPT is set to the −5.18, press START/ENTER, and "SLOPE × 1000 = Ø.ØØ/INC/DEC ENTER/⋆" appears in the display.
6. At this point, the value of SLOPE in %AC per count may be altered if desired. Normally, this is done only to enter data from a previous calibration for the mixture that is being run today.
7. Since we do not wish to alter SLOPE at this time, press START/ENTER, and "SLOPE × 1000 = Ø.ØØ/INTERCEPT = −5.18⋆", the current values of SLOPE and INTERCEPT, are displayed.
8. Press START/ENTER, and "DATA CORRECT?/YES/NO?" will be displayed. This offers a chance to alter the data by pressing DEC/NO.
9. If the data are correct, press INC/YES, and "SELECT/FUNCTION ⋆" appears.

CALIBRATE %AC OFFSET EXAMPLE (MIX)

Offset of the %AC of the CALIBRATION PANS can be accomplished if the %AC used during calibration is found to be in error. The following table contains typical results:

Original Data:	CALPAN1 = 4.00%	CALPAN2 = 6.00%
	CALCNT1 = 2149	CALCNT2 = 3431
Corrected Data:	CALPAN1 = 3.97%	CALPAN2 = 6.05%
	CANCNT1 = 2149	CALCNT2 = 3431

The CORRECTED DATA indicate a change in the values assigned to each of the sample's %AC. To modify the gauge calibration to reflect these changes, the CALIBRATE OFFSET FUNCTION is used. This routine will update the 3241's internal calibration quickly without requiring a time-consuming rerun of the CALIBRATE routine.

%AC OFFSET PROCEDURE

1. Rotate FUNCTION switch to CAL OFFSET and "CALIB OFFSET/PROCEDURE ⋆" appears.
2. Press START/ENTER, and "SLOPE/INTERCEPT/OFFSET? YES/NO" appears on the display.
3. Press DEC/NO, and the 3241 proceeds to the %AC/COUNT OFFSET routine with the message:

   "CALPAN1=4.00%/INC/DEC ENTER/⋆"
4. Press INC or DEC to obtain the desired value CALPAN1 = 3.97%.

5. Press ENTER, and the count corresponding to PAN1 appears as

"CALCNT = 2149/INC/DEC ENTER/⋆".

6. Press ENTER, and the %AC for PAN2 appears as

"CALPAN2 = 6.00% /INC/DEC ENTER/⋆".

7. Press INC or DEC to obtain the desired value CALPAN2 = 6.05%.

8. Press ENTER, and "CALCNT2-3431 / INC/ DEC ENTER/⋆" appears.

9. Press ENTER and "SLOPE × 1000 = 1.62%
INTERCEPT = .48 ⋆"
appears.

***** THIS IS THE *NEW* 3241 CALIBRATION! *****
***** THIS DATA AND INFORMATION ON THE *****
***** CALIBRATION PANS SHOULD BE *****
***** RECORDED FOR FUTURE REFERENCE *****

10. Press ENTER and "DATA CORRECT? / YES/ NO" appears.

***** A DEC/NO RESPONSE WILL CAUSE *****
***** THE 3241 TO REPEAT THIS *****
***** PROCEDURE BEGINNING AT STEP 2. *****

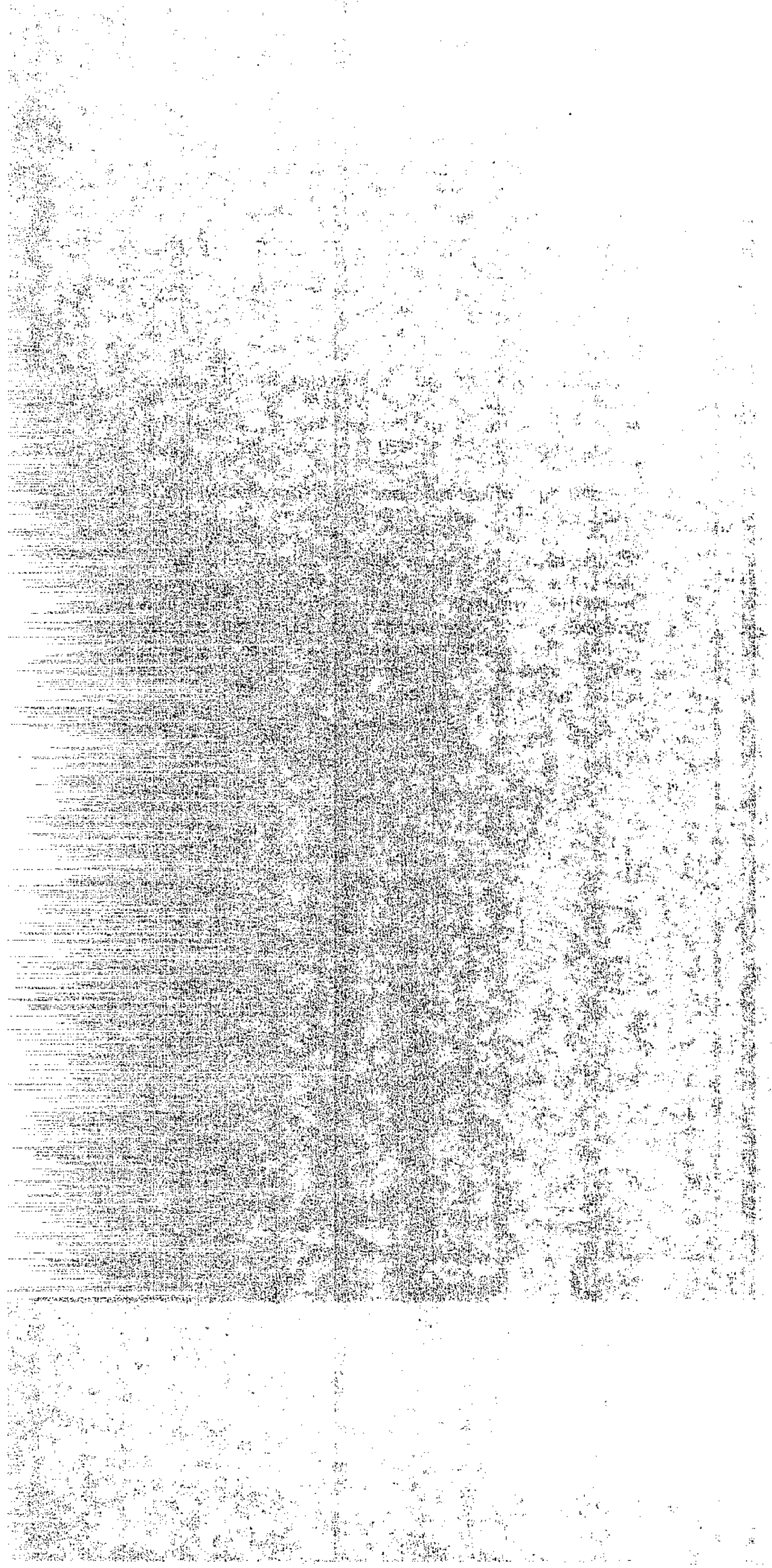
11. Press INC/YES and "SELECT / FUNCTION *" appears.

12. Rotate FUNCTION switch to the desired mode of operation.

Notes:

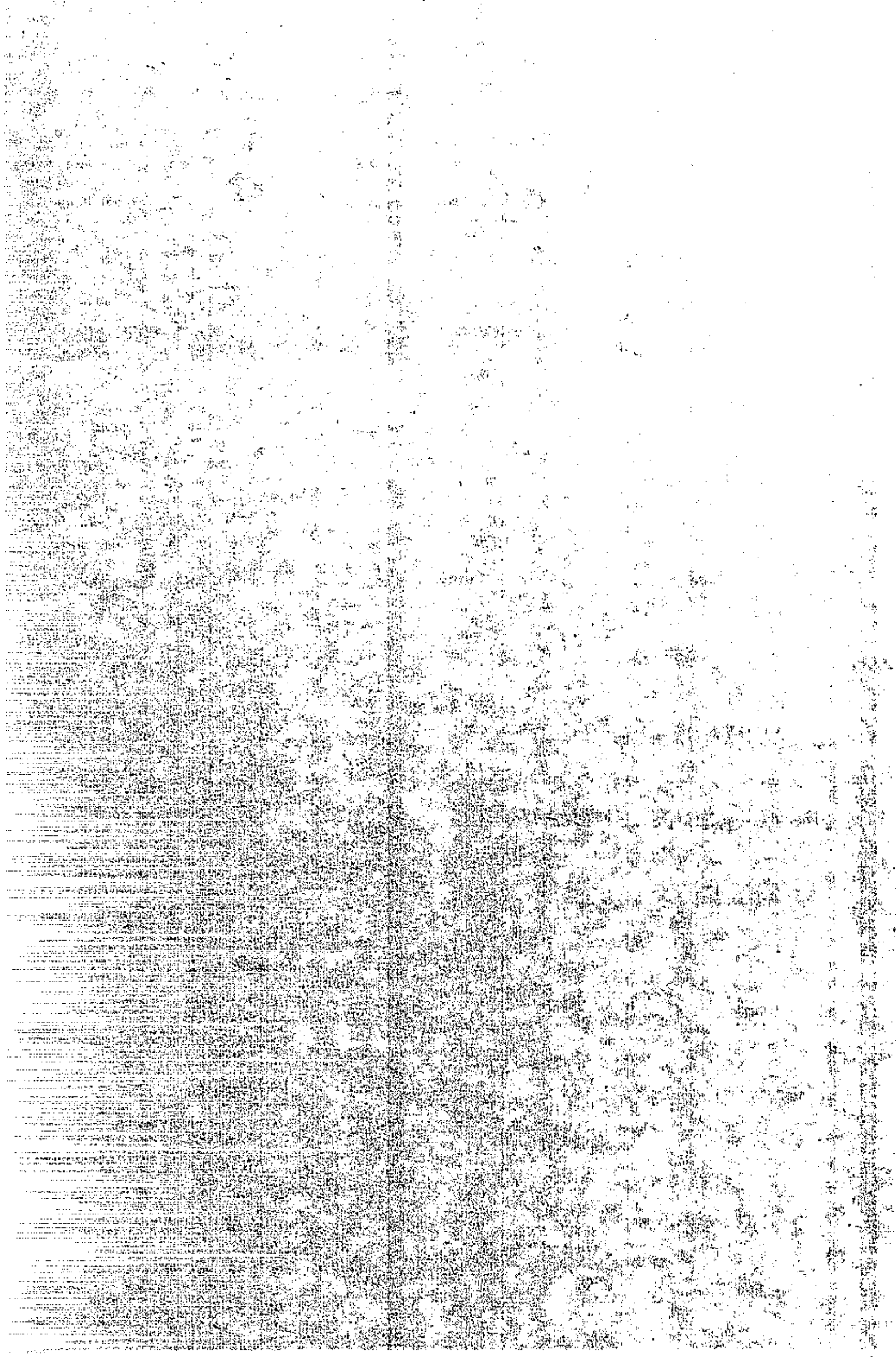
An alternate and simple method to correct for moisture and the only way available when working with a drier drum plant is to use the microwave moisture method, Calif. T.M. 370 as described in Pt. III, A, 2i.

A daily use of the reference pan supplied with the gauge should be done. This is a quick check of the gauge components and will alert the operator to any adverse changes to the gauge's reliability. A general rule is the gauge readout should be within ±2% of the value supplied by Troxler for that gauge and reference pan. Background radiation can cause some variation to the supplied readout. If there is a variation of ±5% or more, contact the Troxler service facility for further advice.



APPENDIX - B

RECYCLING AC CONTAINING FABRIC



General

Recycling of AC pavements is gaining momentum as the cost of materials and energy escalate. At the same time, the types of paving fabrics used and their frequency of installation in AC pavements are increasing. Therefore, study was conducted to determine the effect paving fabrics might have on the recycling process.

Phase I of this study consisted of examining the effects that four different fabrics have on the milling of the AC pavement.

Phase II dealt with the effect of milled fabric particles on recycle mix design laboratory testing and the mechanical properties of the recycled AC mix.

Phase I: Milling of AC Containing Fabric

The section of roadway chosen for this phase of the study was originally constructed of PCC in 1960 and was reconstructed in 1980 with a 0.35 foot-thick asphalt concrete (AC). It contains 1500 foot test sections of four brands of fabric; Bidim C-22, Fibretex 200, Petromat, and TrueTex MG75.

On July 22, 1982, a section of AC 300 ft long by 55 in. wide, was milled from each of the four fabric areas. The milling machine used was a CMI PR225 Rotomill. Two different types of Kennetal cutting bits - a cone-shaped rotating bit (C3 Model) and a chisel-shaped nonrotating bit (CS2 Model) - were used on each fabric section. Following a preliminary pass to remove the top 0.10 ft of AC, three different types of cuts were made in each fabric section:

0.15 ft (to 0.05 ft below the fabric) at fast travel speed (20 to 25 ft/min.)

0.15 ft (to 0.05 ft below fabric) at slow travel speed(5 to 8 ft/min.)

0.25 ft (to the PCC pavement) at the fastest speed possible.

The weather during milling was hot and clear with the air temperature 75° to 95°F.

In general, the fabric did not present a problem for the roto-milling operation (Figures 1B-9B). All four fabrics did accumulate on the middle third of the mandrel, but this did not appear to affect the cutting function of the mandrel for the depths and length of cut tested. It appeared, however, that in a larger project, the mandrel would have to be cleaned periodically. It is also suspected that in cooler weather this accumulation would have been somewhat reduced.

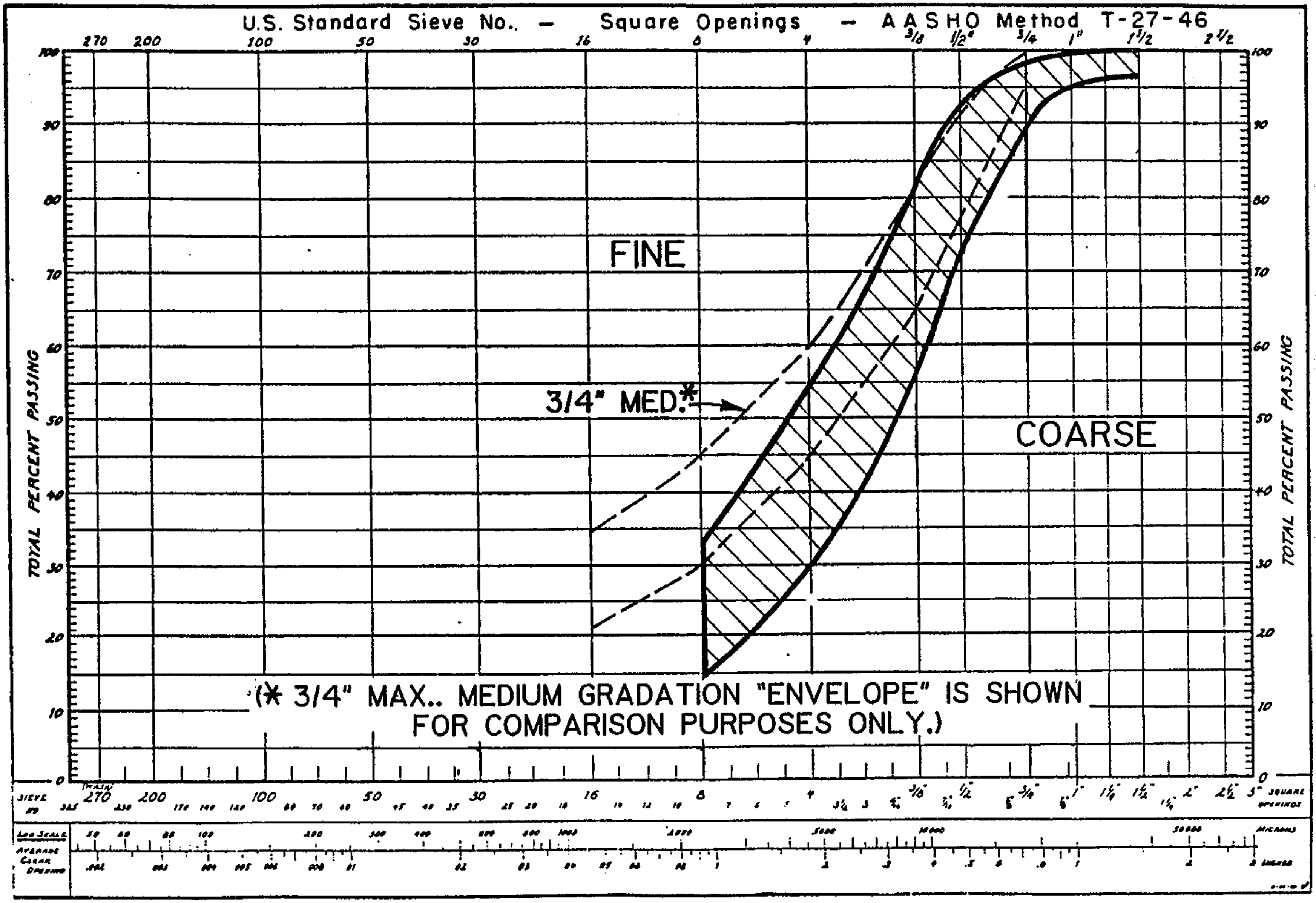
A field survey of the fabric particles that were left in the windrow after roto-milling revealed that there was some maximum particle size differences (Table 1B) depending on the travel speed, tooth-type and fabric. Conclusions drawn from this phase of the investigation are:

(1) The presence of fabric in an AC pavement does not seriously affect milling (removal) of the pavement.

(2) The maximum fabric particle size resulting from the four fabrics milled was 1 in. x6 in., which occurred at a fast milling speed.

State of California
TRANSPORTATION LABORATORY

SEMI-LOG CHART FOR GRADING CURVES



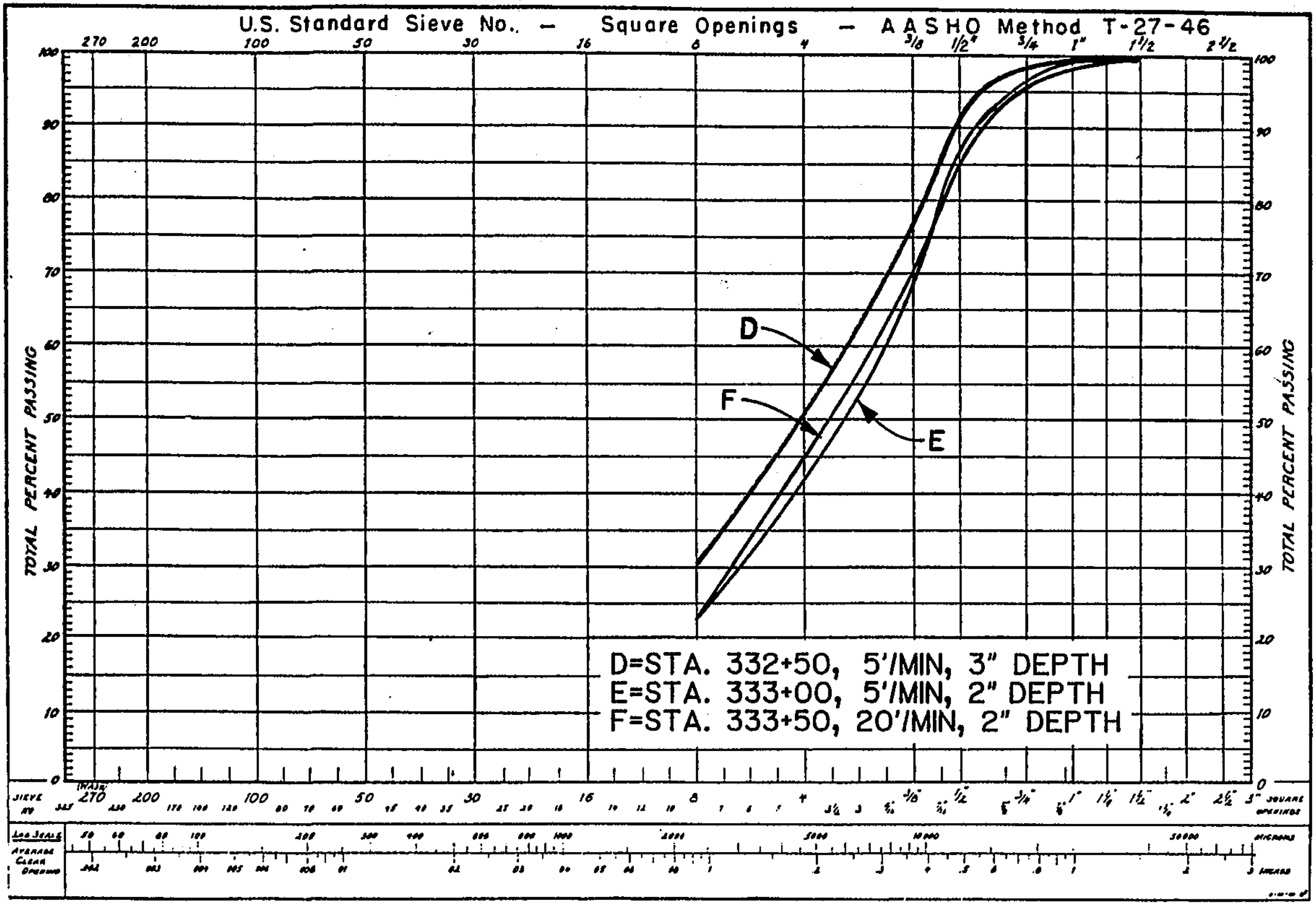
TL-216 (Rev. 7/82)

RAP GRADATION EXTREMES

FIGURE 1B.

State of California
TRANSPORTATION LABORATORY

SEMI-LOG CHART FOR GRADING CURVES

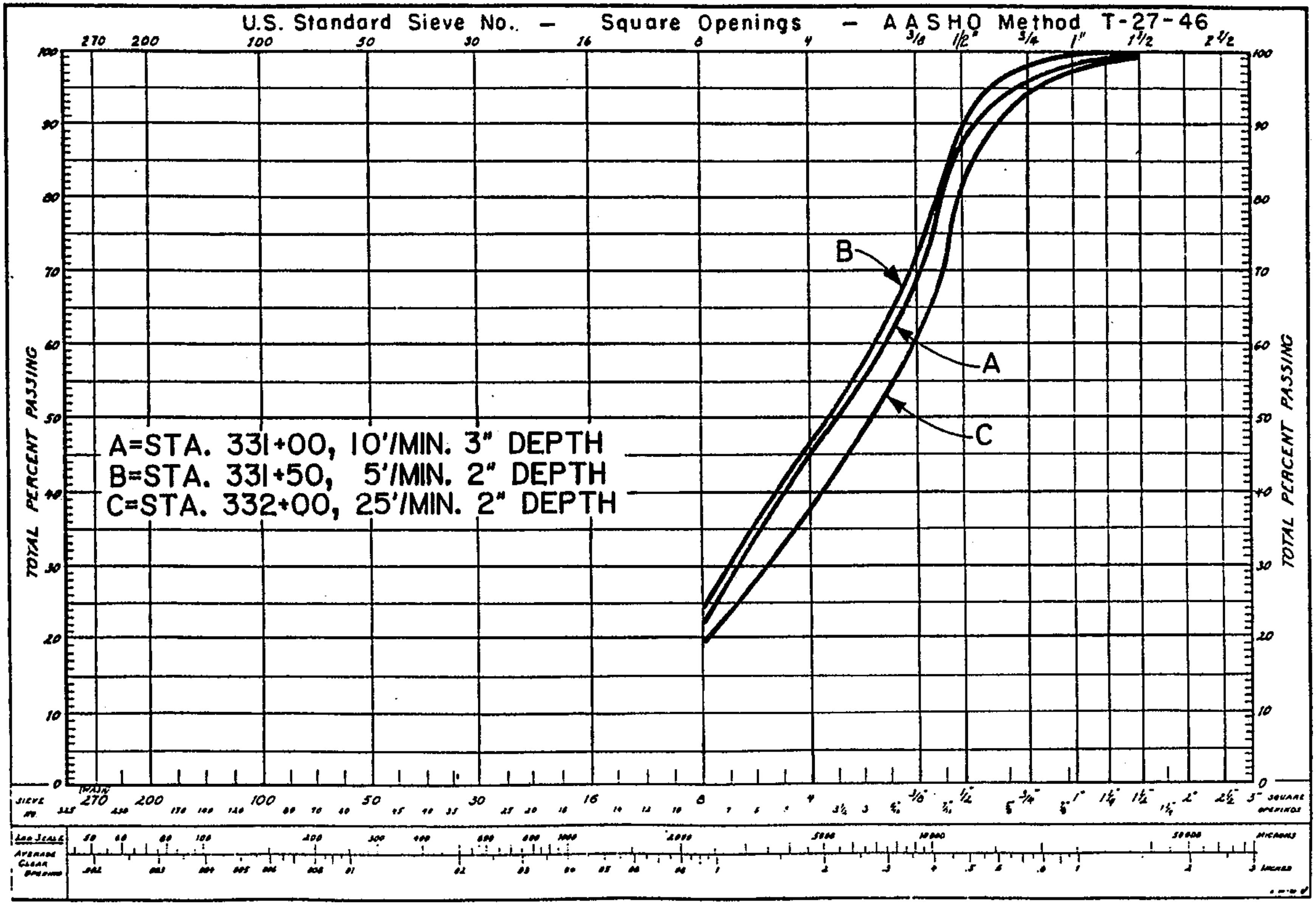


TL-216 (Rev. 7/82)

FABRIC PARTICLE GRADATION (BIDIM C-22, CONICAL TEETH)

State of California
TRANSPORTATION LABORATORY

SEMI-LOG CHART FOR GRADING CURVES



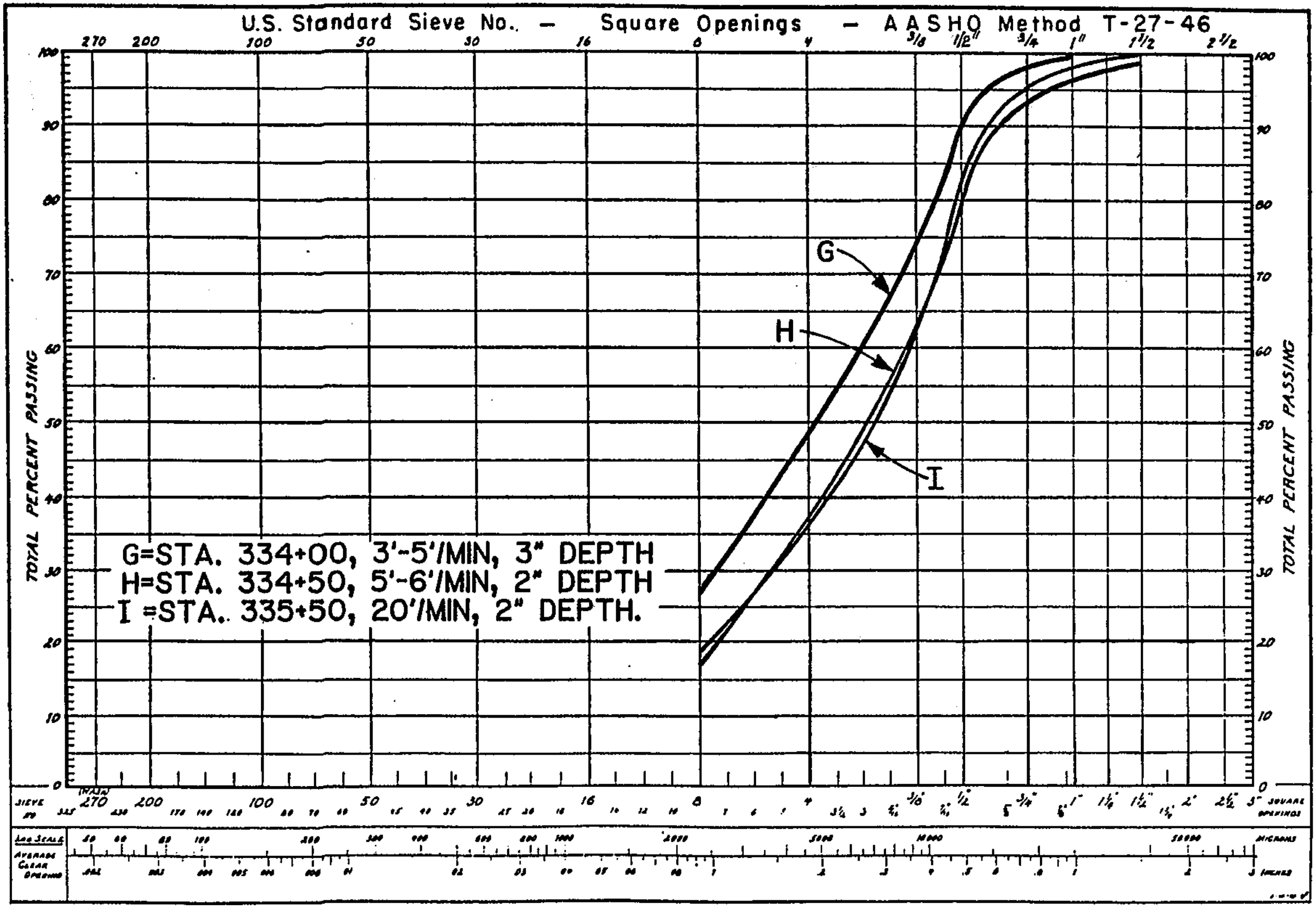
TL-216 (Rev. 7/82)

FABRIC PARTICLE GRADATION (BIDIM C-22, CHISEL TEETH)

FIGURE 3B.

State of California
TRANSPORTATION LABORATORY

SEMI-LOG CHART FOR GRADING CURVES

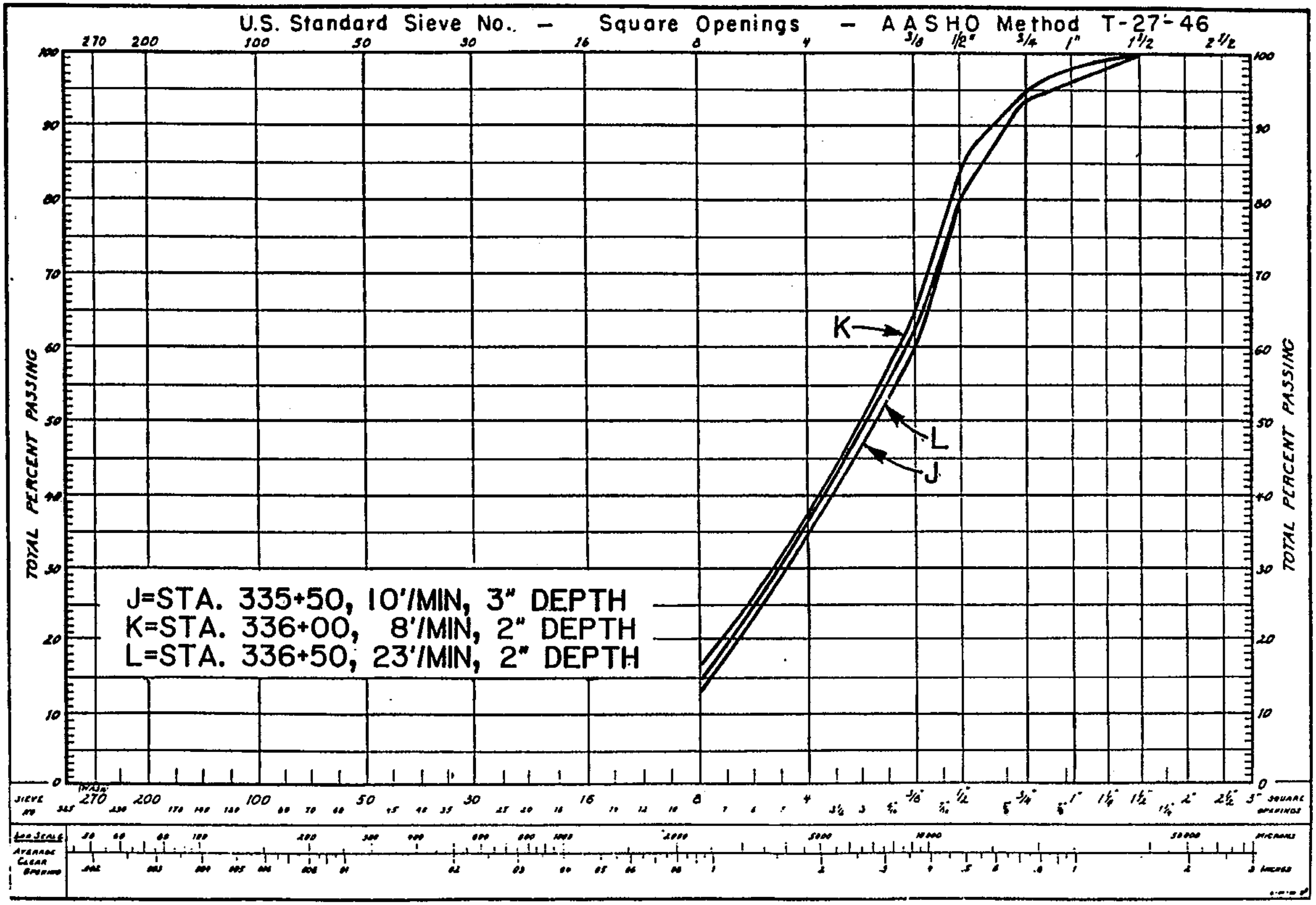


TL-216 (Rev. 7/82)

FABRIC PARTICLE GRADATION (FIBRETEX 200, CONICAL TEETH)

State of California
TRANSPORTATION LABORATORY

SEMI-LOG CHART FOR GRADING CURVES



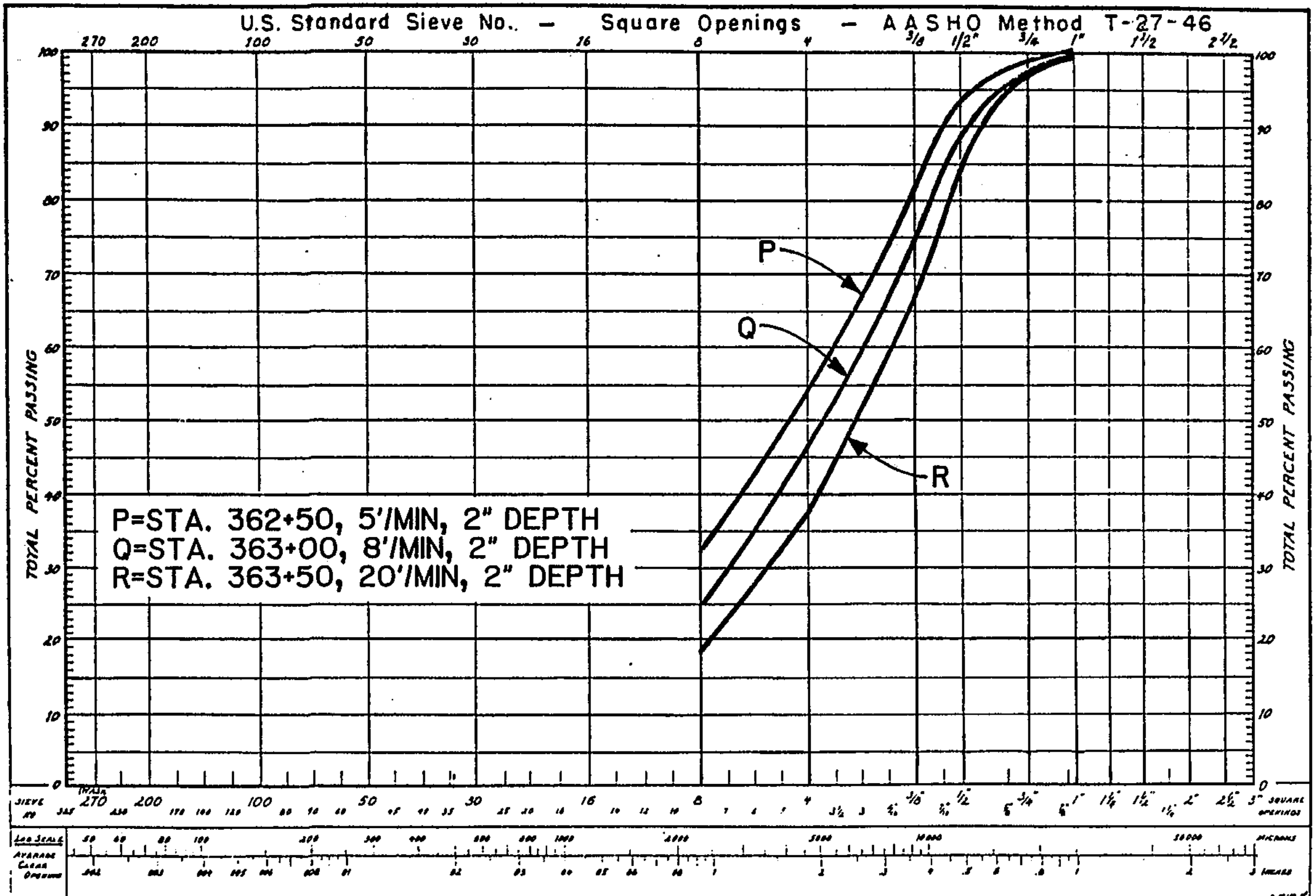
TL-216 (Rev. 7/82)

FABRIC PARTICLE GRADATION (FIBRETEX 200, CHISEL TEETH)

FIGURE 5B

State of California
TRANSPORTATION LABORATORY

SEMI-LOG CHART FOR GRADING CURVES

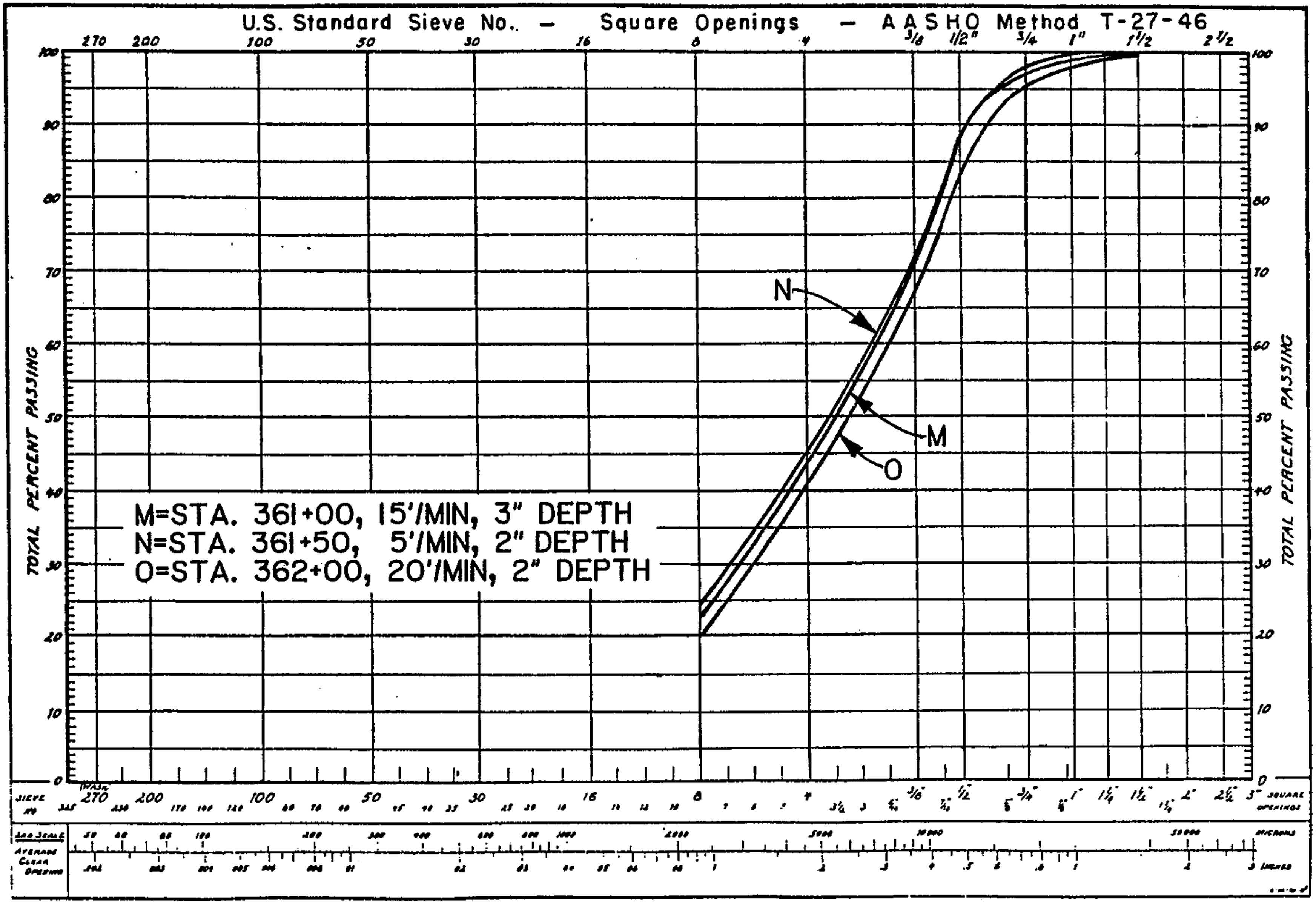


TL-216 (Rev. 7/82)

FABRIC PARTICLE GRADATION (TRUETEX MG-75, CONICAL TEETH)

State of California
TRANSPORTATION LABORATORY

SEMI-LOG CHART FOR GRADING CURVES

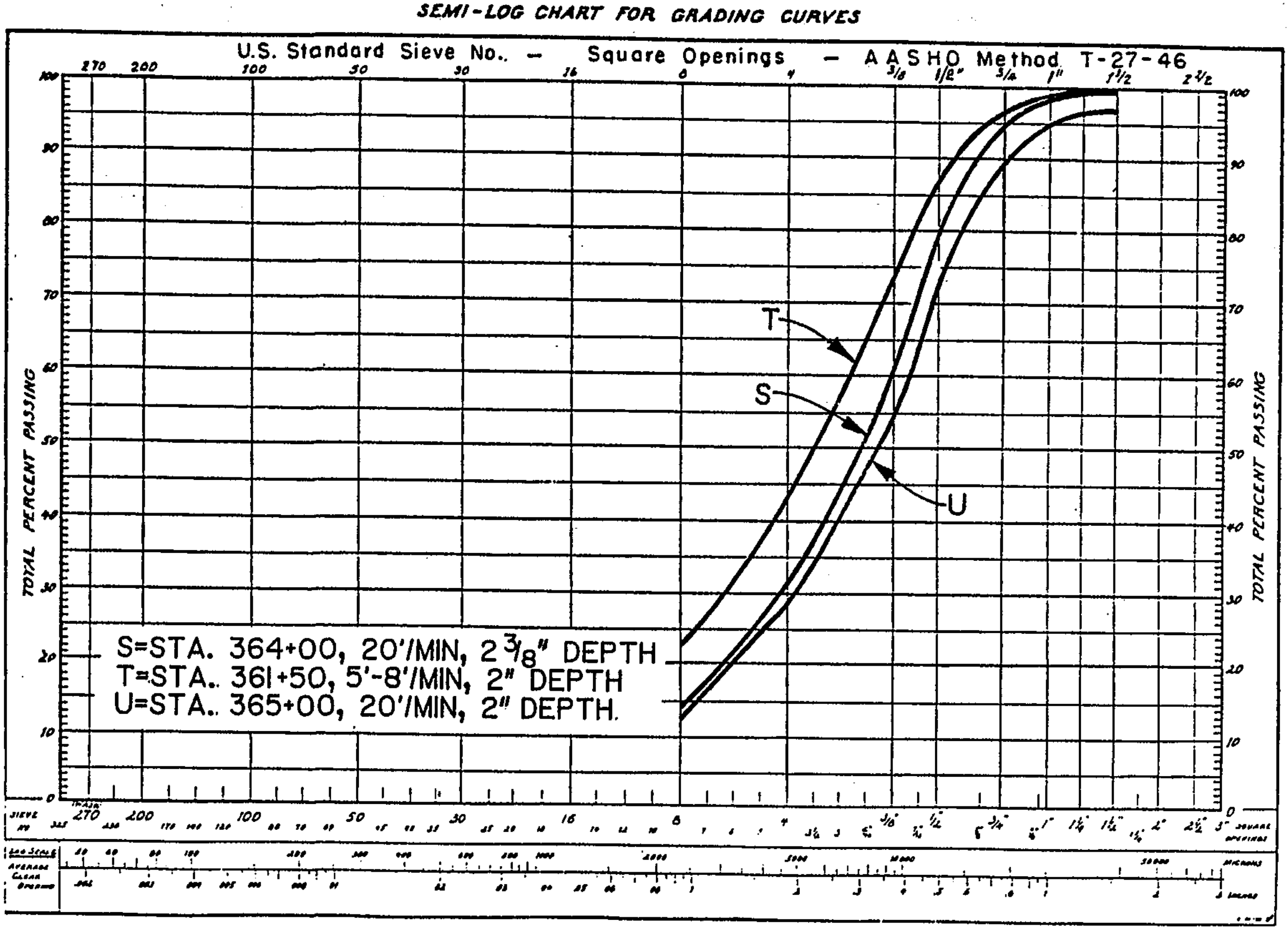


TL-216 (Rev. 7/82)

FABRIC PARTICLE GRADATION (TRUETEX, MG-75, CHISEL TEETH)

FIGURE 7B.

State of California
TRANSPORTATION LABORATORY

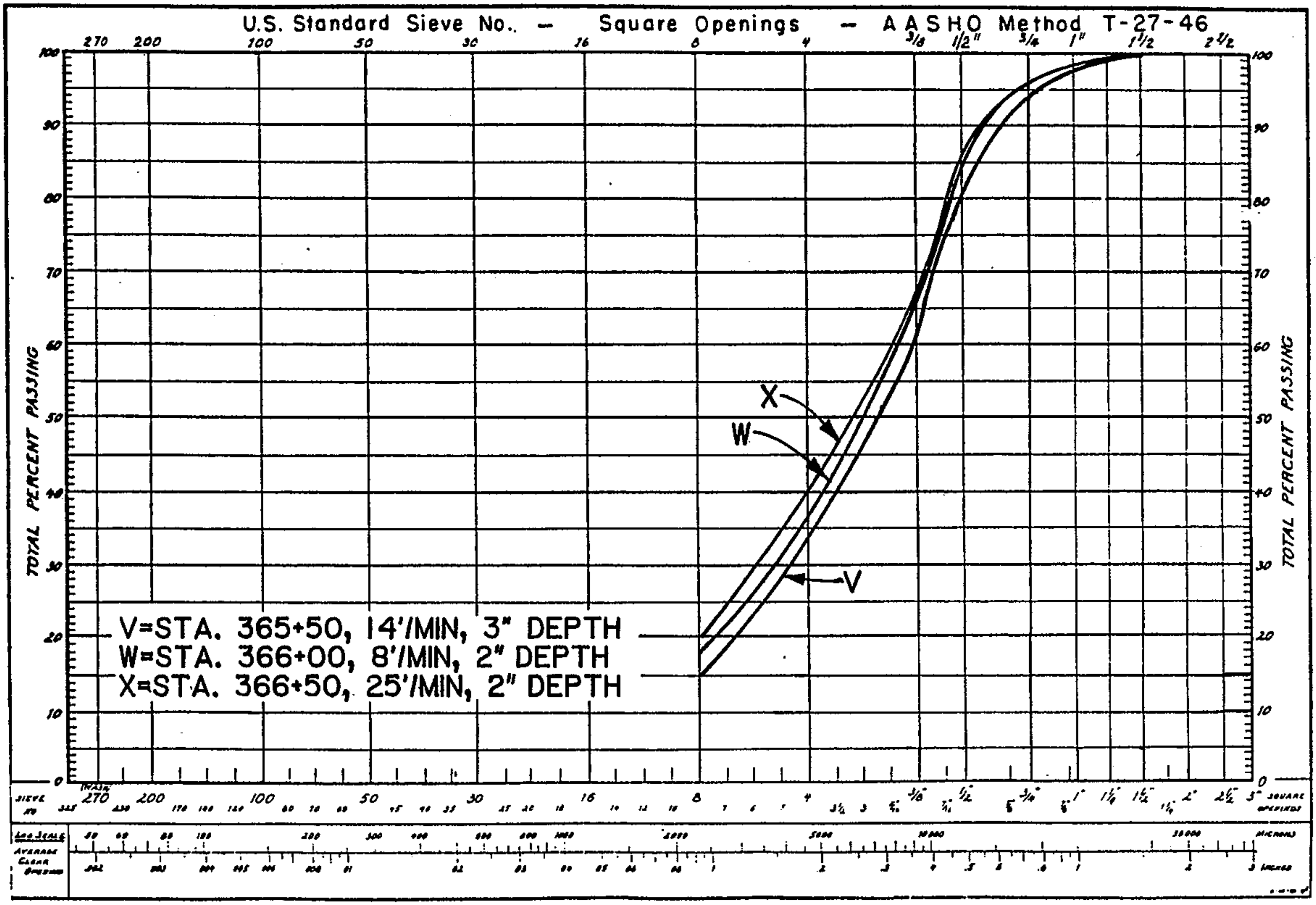


TL-216 (Rev. 7/82)

FABRIC PARTICLE GRADATION (PETROMAT,CONICAL TEETH)

State of California
TRANSPORTATION LABORATORY

SEMI-LOG CHART FOR GRADING CURVES

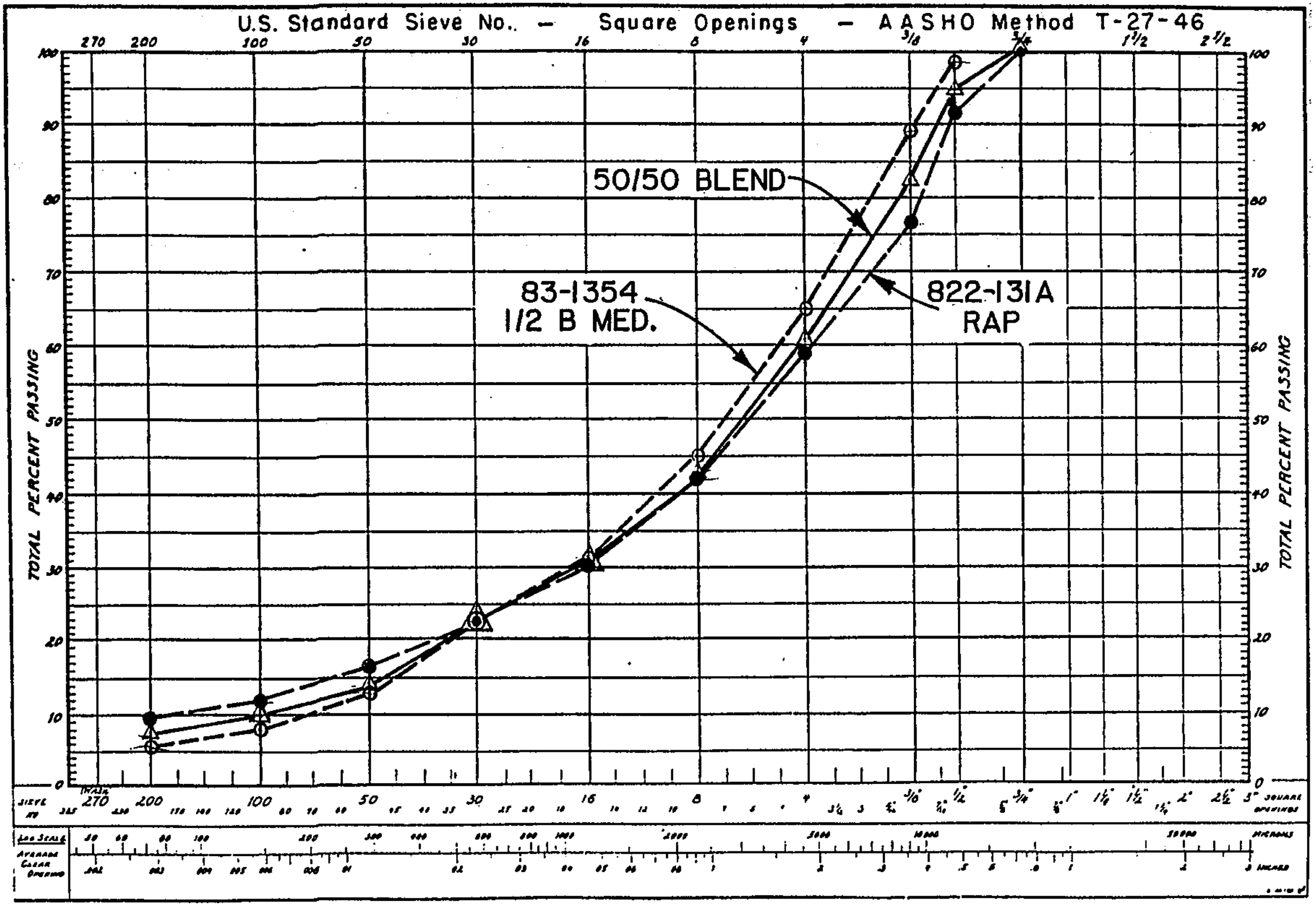


TL-216 (Rev. 7/82)

FABRIC PARTICLE GRADATION (PETROMAT, CHISEL TEETH)

State of California
TRANSPORTATION LABORATORY

SEMI-LOG CHART FOR GRADING CURVES



TL-216 (Rev. 7/82)

HOT RECYCLE GRADATION DATA

(3) The TrueTex MG75 fabric consistently yielded smaller particles than the other three fabrics.

(4) For all four fabrics, the best milling (i.e., smallest fabric particles) occurred with the chisel tooth (CS2) at the slower travel speed.

(5) The depth of cut should be at least .05 ft below the elevation of the fabric to avoid possible shearing and tearing instead of cutting. Depths greater than .05 ft pose no problem. However, milling production may be less when fabric is concerned due to the necessity of cleaning the mandrel, when larger quantities are concerned.

PHASE II: Laboratory Testing

A. INTRODUCTION

The objectives of this phase of the research project were:

1) To determine if the presence of fabric particles in reclaimed asphalt pavement (RAP) hinders the hot and cold recycling mix design process.

2) To determine if the presence of fabric particles in an AC mix affects the laboratory mechanical properties of the mix.

Although the field phase of this study involved the milling of four brands of fabric and milling variables such as speed-of-travel, depth-of-cut, and tooth type, the laboratory testing was limited to a single fabric, Fibretex 200, milled using the conical tooth, at the 0.15 ft milling depth. Reasons for using this approach are presented below:

1) Bidim (Monsanto) and Truetex (TrueTemper) are no longer marketed for paving applications.

2) Fibretex is a continuous filament fabric, the type suspected of being most difficult to recyle.

3) A greater supply of the salvaged AC with Fibretex is available, considering that very similar gradations permitted combining of the salvaged material from the "fast" and "slow" milling sections.

4) An earlier study(32) found that milling to various depths (1 in., 2 in., or 2 1/2 in.) did not produce significantly different fabric gradations.

5) The chisel tooth is not the type commonly used due to its higher cost and because it locks in position and thus wears faster than the conical tooth.

B. GENERAL

Samples of RAP containing the Fibretex 200 fabric were received in July 1982. The samples were scalped on a #4 sieve to remove the large fabric pieces. The entire RAP was then dry graded and it was determined that 100% passed the 3/4" sieve, 44% passed #4, and 0% passed the #200 sieve (Table 1B). All the RAP material was then recombined into appropriate sized test samples (1200 grams $\pm$).

The extracted asphalt content the RAP was determined to be 4.0% by the hot solvent extraction test (California Test 310). The aggregate grading after the extraction test indicated 100% passing the 3/4" sieve, 58% passing the #4, and 8.8% passing the #200 sieve (Table 2B).

The hot extraction (California Test 310) and grading were also run on the scalped fabric pieces and the asphalt content averaged 35% by dry weight of aggregate clinging to the fabric. The after extraction grading results were high in fines with 100% passing the 1/2" sieve, 92% passing the #4 sieve, and 15.7% passing the #200 sieve (Table 2B). During the hot extraction test, the fabric appeared to dissolve completely. There was no problem flushing the solvent out during extraction.

C. DETERMINATION OF OPTIMUM BITUMEN CONTENT (OBC)

1. Recovered Asphalt Test Data From RAP

The Abson Recovery Test procedure (California Test 380) provided asphalt for qualitative analysis. The results were used to determine the theoretical percentage of recycling agent required to be added for both the cold and hot recycling design. The presence of the small fabric particles (passing #4) in the salvaged AC did not affect the running of the Abson Recovery test.

Results of the subsequent tests on the recovered asphalt are presented below:

		AASHTO
Viscosity @ 140°F	28,593 Poises	(T. 202)
Viscosity @ 275°F	1,362 CSt	(T. 201)
Penetration @ 77°F	27 dmm	(T. 49)
Softening Point	147°F	(T. 53)
Ductility @ 77°F	38 cm	(T. 51)

The approximate bitumen ratio (ABR) of recycling agents to be added for the recycling design sets were:

Cold Recycling = 2.8% ERA 75

Hot Recycling = 3.7% AR2000

2. Hot Recycled Mix Design (California Test 377)

Three samples of a 50/50 blend of RAP (no fabric) and virgin aggregate were batched. The gradings are plotted in Figure 10B. Each sample was heated in a 325°F oven for 2 hours, removed from the oven and immediately mixed with a quantity of AR-2000. A quantity equivalent to 3.7% was added to one sample and lesser and greater amounts in 0.5% increments were added to the other samples. The samples were then cured for 16 hours ±1 hour in a 140°F oven.

Test specimens were fabricated and tested as for normal AC mixes. No problems were encountered in mixing, compacting or testing. The final optimum percent of AR-2000 was determined by California Test 377 to be 3.2 (Table 3B).

3. Cold Recycled Mix Design (California Test 378)

The optimum percent of recycling agent to be added for the cold method of recycling was determined by California Test 378. Three representative samples of the RAP (no fabric) were batched and dried to a constant weight in a 140°F oven and then cooled to room temperature. Two percent water by dry weight of mix was added and each sample thoroughly hand mixed. Test samples were prepared by adding a recycling agent in the theoretical amount and lesser and greater amounts in increments of 0.7% were added to other samples. All samples were cured at 140°F for 16 hours (±1 hour).

All samples were then compacted at 140°F in accordance with California Test 378. The optimum bitumen content (OBC) was determined to be 1.2% ERA 25 (Table 4B).

D. DETERMINATION OF EFFECT OF FABRIC PARTICLES ON AC PROPERTIES

1. Fabrication of the Control Briquettes

The fabrication of the control briquettes for the hot recycle AC mix involved a 50/50 blend of virgin aggregate and RAP. The standard curing and compaction sequence was followed (California Test 377). The grade of recycling agent used was AR-2000 and the amount was 3.2% as determined previously from the OBC design set.

The fabrication of the control briquettes for the cold recycle AC mix (100% RAP) involved the standard (California Test 378) curing and compaction sequence. Emulsified recycling agent (ERA) was used, with the amount determined previously by the OBC design set. (1.2%)

2. Fabrication of the Fabric Briquettes

A. Hot Recycle Mixes

Preparation of the hot recycle fabric briquettes (a 50/50 blend of virgin aggregate and RAP) consisted of fabricating 12 briquettes; 6 containing a single 4-inch* fabric piece per briquette, and 6 containing four 1-inch* fabric pieces per briquette. The fabric pieces used were previously scalped from the salvaged AC and then added back into the briquettes in the appropriate quantity. The total weight of the single 4-inch fabric piece and the four 1-inch fabric pieces was the same (13 grams). The fabric added

*Maximum dimension of fabric piece.

to all briquettes in all cases was 1.1% by weight of the aggregate. This represents the percent of fabric expected from a milling depth of 0.15 ft.

The standard curing and compaction sequence of California Test 377 was followed for briquette fabrication except for one deviation the fabric pieces were mixed and cured with the AC mix material. The fabric pieces were then placed by hand on the mechanical spader belt to end up about in the center of the briquette. The fabric pieces did not appear to affect the kneading compaction process.

B. Cold Recycled Mixes

Preparation of the <u>cold</u> recycle briquettes with the RAP material consisted of the fabrication of 12 bri quette-6 briquettes having a single 4-inch fabric piece per briquette and 6 having four 1-inch fabric pieces per briquette.

The fabric pieces used were the same size and total weight (13 grams) as those used in the hot recycle briquettes. The fabric added to all the briquettes was 1.1% by weight of the aggregate. The recommended emulsified recycling agent, (1.2% ERA 25) was used.

The standard curing and compaction sequence of California Test 378 was followed for briquette fabrication except for one deviation - the fabric pieces were mixed and cured with the AC mix material and the fabric pieces were positioned by hand on the mechanical spader belt to be about in the center of the briquette. As with the hot recycle procedure, the fabric pieces had no visible effect on the kneading compaction process.

3. Test Results

All the AC mixes were subjected to the following laboratory tests:

Resilience Modulus (M_R) - -	Chevron Test Method
Stability - - - - - - - - - -	California Test 366
Sp Gr - - - - - - - - - - - -	California Test 308
Cohesion - - - - - - - - - -	California Test 306
Air Voids - - - - - - - - - -	California Test 367
Surface Abrasion Loss - - - -	California Test 360B

Table 5B summarizes the test results for the various mixtures. Although the table shows slight, but consistent decrease in the briquette stability for both hot and cold recycle mixes, it was not significantly different from the control briquette.

Cohesion values for both the hot and cold recycle briquettes with fabric exceeded the cohesion values of the control mixes. The cohesion vlaue for the briquettes with the single 4-inch fabric piece appeared to increase the most. This increase in cohesion values could possibly be attributed to the increase in fines and asphalt content of the mix after the fabric pieces are added. The fabric pieces could also be providing some tensile reinforcement to the AC mix.

The surface abrasion test results were affected by the addition of the fabric in the hot recycle briquettes. A significant improvement (less abrasion) was noted in the hot recycled briquettes with the 1 in. fabric. The surface abrasion results on the cold recycled briquette indicated no great detriment or benefit with the addition of the fabric.

Both control briquettes and briquettes with the 4-inch fabric (from both the hot and cold recycling) were subjected to an Abson Recovery. Table 6B summarizes the tests on the recovered asphalt. It appeared that the recovered asphalt from the hot recycle samples was slightly harder with the addition of the 4-inch fabric pieces.

The results of the recovered asphalt from the cold recycled briquettes indicated some softening of the asphalt.

Table 7B tabulates the extraction and gradation results (after testing) for the cold and hot recycled specimens, both control and with 4-inch fabric added. In comparing the cold recycled briquettes, control and 4-inch fabric sets, a slight increase in asphalt content was noted along with a slightly finer grading. In comparing the hot recycled briquettes, control and 4-inch fabric set, an increase in asphalt content is noted along with grading.

The results of the resilience modulus testing (M_R) indicated slightly higher values with the addition of the fabric pieces in both the hot and cold recycling process.

The calculated percent of air voids decreased greatly with the addition of the fabric pieces in the hot recycling process due to the higher compacted densities of the samples. The calulated air voids remained basically unchanged in the cold recycling process due to unchanged densities with the addition of the fabric pieces.

E. CONCLUSION (Phase II only)

1) The presence of milled pieces of fibers in salvaged AC mix does not hinder the mix design process for either cold and hot recycling.

2) The presences of milled fabric particles in a recycled AC mix (hot or cold) appears to result in a slight reduction of stability and a slight increase in M_R, specific gravity and cohesion. The increase in test values is probably due to the increase in asphalt content cause by the addition of the asphalt-laden fabric pieces. The calculated void content for hot recycled mixtures will show a significant decrease with milled fabric. Void content of cold recycled mixtures is relatively unaffected by milled fabric.

3) No significant differences were observed between test values of briquettes with 1" fabric and 4" fabric pieces.

4) Milled AC with fabric poses no problem for hot and cold recycling mixes.

<u>Table 1B</u>

Maximum Particle Sizes of Roto-Milled Fabrics

Fabric	Cone Tooth (C3)			Chisel Tooth (C52)		
	(a) Depth 0.15'	(b) Depth 0.15'	(c) Depth 0.25'	(a) Depth 0.15'	(b) Depth 0.15'	(c) Depth 0.25'
Petromat	1"x6"	3/4"x4"	No Test	1"x6"	3/4"x2"	1"x4"
Bidim C-22	1-1/2"x6"	3/4"x6"	1/2"x2"	1-1/2"x6"	1/2"x3"	1"x6"
FibreTex 200	1"x6"	1/2"x4"	3/4"x4"	1"x6"	3/4"x1-1/2"	1"x5"
TrueTex MG75	1"x4"	3/4"x1"	Not Sampled	3/4"x4"	1/2"x2"	3/4"x1-1/2"

Note: a. 20 to 25 ft/min,

b. 5 to 8 ft/min,

c. 3 to 5 ft/min,

d. 10 to 15 ft/min,

Table 2B

Effect of Hot Extraction Process on Gradation of RAP and Fabric Pieces

RAP Material As Received		RAP Material After Hot Extraction	Fabric Pieces * After Hot Extraction
Sieve	% Passing	% Passing	% Passing
3/4"	100	100	-
1/2"	88	92	100
3/8"	68	76	97
4	44	58	92
8	22	42	88
16	10	30	67
30	4	22	53
50	1	16	37
100	-	12	25
200	-	8.8	15.7
		4.0	35.0

*Note: All fabric prior to extraction was retained on the #4 sieve.

Table 3B

Hot Mix Design Data

TYPE BITUMEN	AR-2000			
Asphalt Ratio (%)	3.2	3.7	4.2	4.7
Flushing	None	Slight	Moderate	Heavy
Stability	44	41	33	29
Specific Gravity	2.40	2.40	2.41	2.43
Cohesion (g/in.)	346	343	315	212
Voids	4.6	3.9	2.9	1.2

Remarks: Recommended Optimum = 3.2% AR-2000

Table 4B

Cold Mix Design Data

Type of Recy. Agent	ERA 75					ERA 25**
Recycling Agent Ratio (%)	0.4	1.2	2.0	2.8	3.6	1.2
Asphalt Residue Ratio (%)	0.2	0.7	1.2	1.7	2.2	0.7
Premix Moisture %	——— 2.0 ———					
Compaction Temp. (°F)	——— 140 ———					
Flushing	None	Slight	Mod	Mod Hvy	Hvy	None
Stability	27	28	28	26	-	27
Specific Gravity	2.30	2.34	2.35	2.38	2.38	2.34
Cohesion (g/in.)	116	114	1.30	135	124	135
Voids (%)	8.7	6.4	5.6	3.6	2.9	6.4
Optimum %		X				

Remarks - Optimum Recy. Agent by orignal design = 1.2% ERA 75

**Replotted optimum recycled agent on nomograph, changed the recycling agent from ERA 75 to ERA 25.

Table 5B

Mechanical Property Test Results

	Hot Recycle	Hot Recycle		Cold Recycle	Cold Recycle		Test
	Control	W/1" Fabr.	W/4" Fabr.	Control	W/1" Fabr.	W/4" Fabr.	Method
Recy. Agent (%)	3.2% AR-2000	3.2% AR-2000	3.2% AR-2000	1.2% ERA 25	1.2% ERA 25	1.2% ERA 25	-
Stability	(39)* 38 39 40	(35) 36 34 34	(34) 36 33 34	(27) 28 26 27	(25) 26 23 25	(24) 26 23 23	TM 366
Cohesion (g/in.)	(224) 222 210 240	(234) 226 240 237	(324) 280 305 386	(135) 145 138 122	(146) 135 145 157	(167) 195 137 170	TM 306
Specific Gravity	(2.34) 2.34 2.33 2.35	(2.41) 2.41 2.40 2.42	(2.42) 2.41 2.41 2.43	(2.34) 2.34 2.34 2.34	(2.34) 2.34 2.34 2.33	(2.34) 2.33 2.33 2.35	TM 308
Voids (%)	(7.1) 7.1 7.5 6.8	(4.4) 4.4 4.8 4.0	(4.1) 4.4 4.4 3.6	(6.4) 6.4 6.4 6.4	(6.5) 6.4 6.4 6.8	(6.5) 6.8 6.8 6.0	TM 367
MR (psi x 105)	(3.38) 2.90 3.03 4.15	(3.41) 3.34 3.41 3.48	(3.60) 3.67 3.13 4.00	(1.64) 1.59 1.79 1.54	(1.99) 1.96 2.04 1.96	(1.84) 2.13 1.68 1.72	Chevron Method
Surf Abras. Loss (g)	(40.5) 33.7 39.4 48.5	(27.3) 26.7 24.7 36.3	(35.4) 39.5 30.5 36.3	(48.8) 46.0 44.8 55.6	(51.9) 44.8 53.9 50.5	(44.4) 42.2 45.2 45.9	TM 360B
Flushing	None	None	None	None	None	None	-

*()Average